Self-aligned Edge Contacts for 2D Layered Systems

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Introduction: Two dimensional (2D) layered materials including graphene, transition metal dichalcogenides and their hetero-structures are promising future materials for various electronic and optical applications [1]. However, making low resistive contacts to these layered systems remains challenging due to the large tunneling resistance between layers which are weakly bonded by van der Waals forces [2]. In this paper, we use few layer graphene as an example to demonstrate the advantage of using an edge contact scheme with a novel self-aligned lithography process. Bypassing the interlayer tunneling resistances, two times lower contact resistances are achieved compared with conventional devices with top contacts.

Device Fabrication: Single and few layer graphene were mechanically exfoliated on a 90nm SiO_2/p++ Si substrate. The graphene layer thickness was identified by optical contrast [3] and also verified by AFM and Raman. E-beam lithography and O_2 RIE were used to define the device channels. Four-terminal electrodes were defined by another e-beam lithography step and a 1nmTi/20nmPd/10nmAu metal stack was deposited. Fig. 1 (a) shows the SEM picture of a final top contacted device. After electrical measurements, edge contacts were fabricated on the same graphene channel for direct comparison as following: 1) an e-beam lithography step defines open PMMA windows close to the S/D top contacts. Half of the widow lies on the metal contact and the other half sits on the graphene channel. The subsequent O_2 RIE removed graphene in the window and fresh graphene edges were exposed. An additional PMMA developing step was added to uncover some graphene area for additional contact coverage. By tuning the over-developing time, the actual graphene-metal contact length can be precisely controlled, as shown in Fig.1 (b). The final S/D contact structure consists of an edge contact in connection with a top contact with well controlled area.

Measurement Characterization: Transfer characteristics of two representative devices with five- and two-layer graphene are presented in Fig. 2 for both conventional top contacts and edge contacts. Significant current improvement is observed in edge-contacted devices. Contact resistance are extracted from four-terminal measurement and presented in Fig. 3. Compared to top contacted devices, the contact resistances are lowered by a factor of two in edge-contacted devices. This improvement is attributed to the self-aligned fabrication process allowing us to accurately position metal contacts at graphene edges within the transfer length. Bypassing the large tunneling resistances, the current can be directly injected to each graphene layer. Interestingly, as the contact length of the exposed graphene gets scaled down from 100nm to 60nm, device currents decrease as shown in Fig. 4, which can be a result of the shorter contact length and loss of edge contacts due to over-etching in the O_2 RIE process.

Conclusion: We demonstrated a novel self-aligned edge contact scheme for few layer graphene devices and 2X on-state current improvement is achieved. The same fabrication process can be easily applied to other 2D layered material stacks for high performance electronic and optoelectronic applications.

Reference: [1] K. S. Novoselov et al , *Phys. Scr.* **T146,** 014006 (2012) [2] Y. Sui et al. *Nano Lett.* **9,** 2973–7 (2009) [3] P. Blake et al. *Appl. Phys. Lett.* **91,** 063124 (2007)

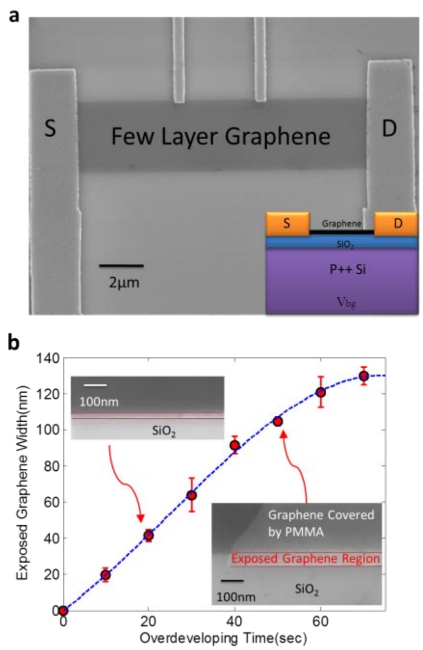

Fig.1 (a) SEM image of a four-terminal few layer graphene device. Bottom inset is the device cross-section schematic. (b) Exposed graphene contact region length vs. over-developing time. Insets are SEM pictures of exposed graphene regions with different overdevelopment time.

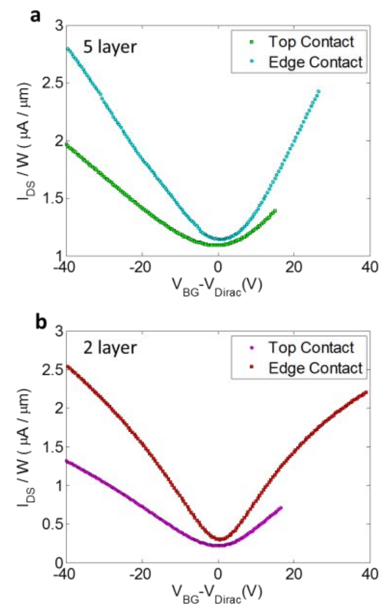

Fig.2 (a) Transfer characteristics of a top-contacted (green) and an edge-contacted (blue) 5-layer graphene FET. (b) Transfer characteristics of a top-contacted (purple) and an edge-contacted (red) bilayer graphene FET.

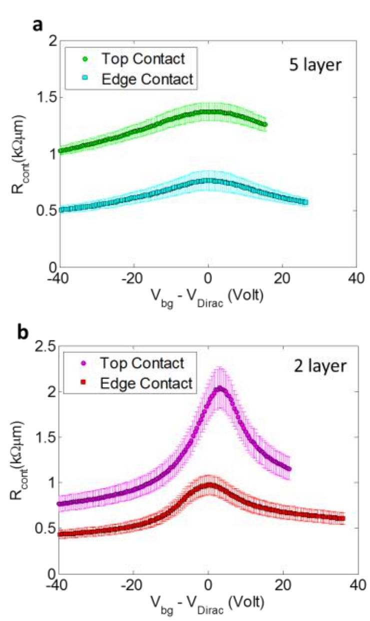

Fig.3 (a) Contact resistance comparison of a 5-layer graphene FET with top contacts (green) and edge contacts (blue). (f) Contact resistance comparison of a bilayer graphene FET with top contacts (purple) and edge contacts (red).

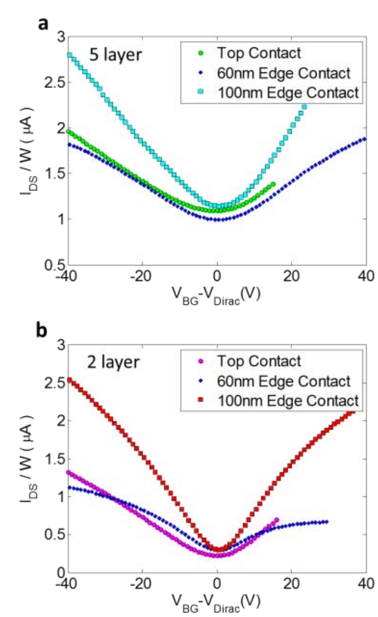

Fig.4 Comparison of transfer characteristics of few layer graphene FETs with top contacts, edge contacts with 60nm and 100nm exposed graphene lengths. Scaling down the exposed graphene length resulted in decreased current.

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