Synthesis, Properties and Tunability of Lateral 2D Heterostructures

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Heterogenous combinations of two-dimensional (2D) layered materials provides us with an ability to tune properties tailored for specific applications. Transition metal dichalcogenides (TMDs) are attractive 2D materials in the "beyond graphene" realm of materials. Low resistance contacts are instrumental to utilize their unique electronic properties. Graphene is a promising candidate and has been shown to produce low-resistance contacts to a few TMDs[1] via manual stacking. We have developed a reproducible method to grow lateral heterostructures of graphene and TMDs like MoS_2, thus allowing for the graphene to be used like an "as-grown" near-Ohmic contact[2]. Here, we discuss electronic properties resulting from the interface of these as-grown lateral hetero-structures.

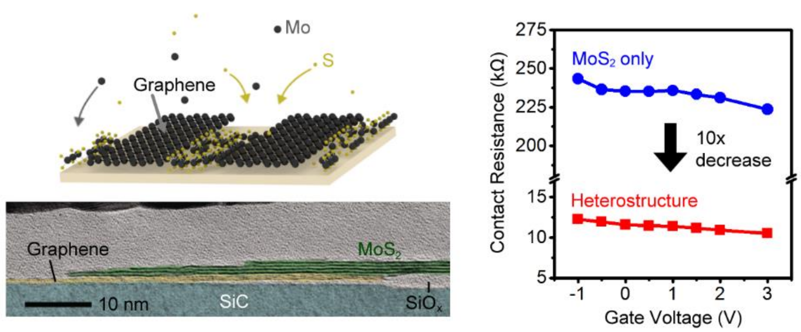

Figure 1: Upper left - Schematic showing the growth of MoS_2 on patterned graphene. Lower left – Cross sectional HRTEM image showing the overlap of the graphene and MoS_2 at the heterostructure interface. Right – Contact resistance reduction via introduction of as-grown graphene contacts to MoS_2

Cross sectional high-resolution transmission electron microscopy is able to demonstrate that the actual interface is a vertical overlap (a few hundred nms) of the MoS_2 onto the edge of the graphene pattern. The van der Waals stacking is maintained at the interface, leading to a pristine and unique combination, which allows for the reduced contact resistance to MoS_2 using graphene as the contacting material instead of conventional metals like Ti/Au. The flexibility of being able to tune the doping of the epitaxial graphene allows us to explore the option of type-matching the graphene contact to the TMD, thus reducing the barrier for electrons and making contacts much superior to conventional metals. This study also explores the impact of this interface in electronic band alignments via low energy electron reflectivity and temperature dependent current measurements.

[1] Das, S. *et al. Nano Lett.* **14,** 2861–2866 (2014). [2] Subramanian, S. *et al.* Carbon (Accepted, 2017)

Supplementary Page

The process of growth of lateral heterostructures and subsequent fabrication of their devices has been elucidated below in Figure 1S:

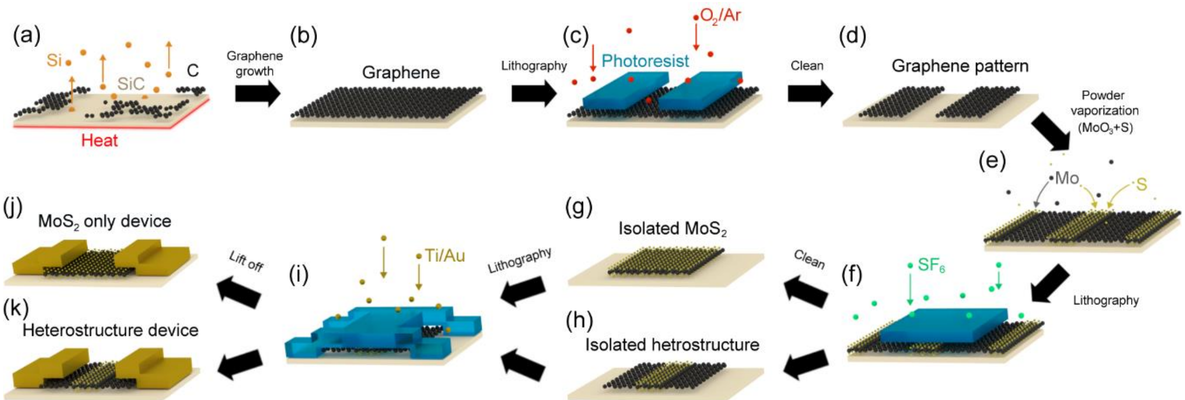

Figure 1S: Process flow of the EG-MoS_2 heterostructure fabrication process – (a) Upon application of heat, the silicon from SiC sublimes and the carbon that is left behind reconstructs to form a uniform layer of graphene as shown in (b). Photolithographic patterning employing a double stack of photoresist (PMGI SF6 + SPR 3012) is used, followed by an O_2/Ar reactive ion etch as in (c). (d) shows the patterned graphene substrate, which is then used to grow MoS_2 via powder vaporization (MoO_3 + S) in a quartz tube furnace. (f) shows photolithographic patterning and exposure to an SF_6 plasma to create isolated heterostructure channels, as in (h) and prevent unwanted current flow. (g) shows a similar control isolated channel of only MoS_2. Step (i) shows the photolithographic patterning and electron-beam deposition of Ti/Au (5/15 nm) which is subsequently followed by lift-off in a resist remover (acetone followed by PRS 3000) to obtain the two test devices: (j) MoS_2 only device; and (k) EG/MoS_2/EG back-to-back heterostructure device.