Bottom-up fabrication of graphene nanoribbons: from ultra-high-vacuum to device integration

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Graphene nanoribbons (GNRs) show exciting properties deriving from electron confinement and related band gap tunability[1]. The ability to tune GNRs' electronic and magnetic properties at the single atom level makes them an ideal platform for a wide range of device applications, from classical transistors to spintronics. In this contribution, we will show the necessary steps to bring GNRs from ultra-high vacuum (UHV) to device integration. After growing GNRs via bottom-up approach on gold substrates, we transfer them using a polymer-free[2] and/or an electrochemical delamination method[3]. We strongly rely on Raman spectroscopy to investigate GNR's quality, orientation and length after substrate transfer. Our Raman studies demonstrate that a length-dependent, Raman-active low-energy vibrational mode is present in all families of AGNRs and provides information on their length as well as overall structural integrity of the ribbons[4]. Additionally, we study the impact of air exposure on GNRs' zigzag edges by measuring GNRs in UHV and after exposure to ambient conditions. These process steps allow us to integrate high quality 9- and 5-AGNR into short channel field-effect transistors (FETs). Using aligned 9-AGNRs as channel material we demonstrate FETs with high on-current I_{on} > 6μA at V_d = 0.1 V and high I_{on}/I_{off} ratios of ~10^4 along with device yield of 80-100%, due to the GNRs' orientation along the source-drain axis of the devices. GNR-FET devices using short 5-AGNRs (2-5 nm) as channel material and graphene as electrodes show linear I-V curves (metal-like behavior) at room temperature[5], while long 5-AGNRs (~20 nm) integrated into FETs with Pd as contacts behave as a semiconductor.

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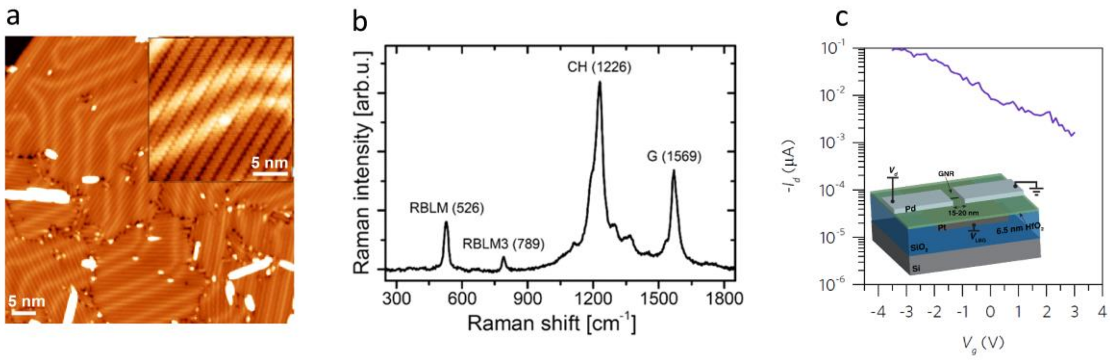

Figure 1: Characterization of 5-AGNRs a) STM b) Raman spectroscopy c) I-V characteristics (inset: device configuration)