Bottom-up fabrication of graphene nanoribbons: From molecules to devices

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Atomically precise graphene nanoribbons (GNRs) exhibit a sizeable bandgap, which is inversely proportional to their width[1], and thus potentially overcome many of the limitations of graphene in electronic device applications. Despite their exceptional properties, significant challenges remain for GNR fabrication, processing and characterization. Bottom-up synthesis of graphene nanoribbons is most commonly performed under ultra-high vacuum conditions, which is one of the bottlenecks in the further technological advancement of this material. Additionally, little is known about the stability of ultra-narrow GNRs under ambient conditions or during device processing. In this work we focused on 9-atom wide armchair GNRs (9-AGNR) grown under high to ultrahigh vacuum conditions on 200 nm Au(111)/mica substrate and vicinal Au(111212) crystal. High resolution STM images show 9-AGNRs with an average length of 50 nm. The GNRs were transferred from the Au growth surface to SiO_2/Si using two transfer approaches. For transferring GNRs from vicinal crystal Au(111212) an electrochemical delamination method was applied, which allowed the GNRs to preserve their structure, overall quality and orientation upon transfer. Detailed characterization of GNRs transferred by this method will be addressed. GNRs from Au/mica substrates were transferred using a membrane-free method. Raman spectra indicate no significant degradation of GNR quality, reveal a homogeneous GNR distribution on the target surface and also showed GNRs had remarkably stability under ambient conditions tracked over a 2-year period. Multi-wavelength Raman studies (785 - 457 nm) reveal the absence of dispersive behavior for the *G*, *D* and *RBLM* modes. The comparison between experimental and DFT-based Raman simulations will be discussed. Finally, we report the fabrication of short channel (L_{ch} ~20 nm) GNR-FET devices using 9-AGNRs as channel material (predicted band gap of 2.1eV)[2]. We demonstrate FETs with high on-current I_{on} >1 μA at V_d = -1 V and high I_{on}/I_{off} ratios of ~10^5. In a next step, GNR-FET devices were produced using graphene electrodes, with a channel length of 1-5nm. A performance of I_{on} > 6μA at V_d = 0.1 V and high I_{on}/I_{off} ratios of ~10^4 was observed.

References

[1] J. Cai *et al*., Nature, **466**, 2010.
[2] J.P. Llinás *et al*. Nature Comm, **8**. 2017

Figures

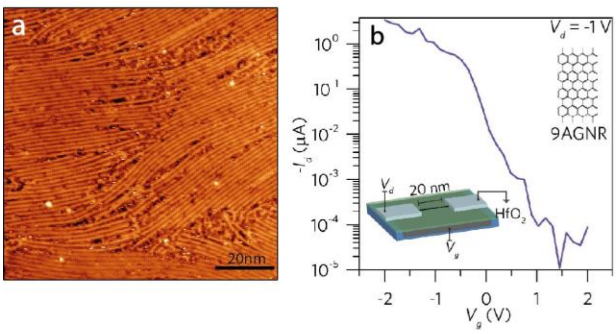

Figure 1: . a) *High resolution STM of 9-AGNRs on Au growth substrate*, b) I_d-V_g curve of 9-AGNR-FET devices