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 5-atom wide armchair GNRs (5-AGNR) grown under high to ultrahigh vacuum conditions on vicinal gold surfaces (Au(788)). High resolution STM images show 5-AGNRs with lengths between 2-10 nm. The GNRs were transferred from the Au growth surface to SiO_2/Si using an electrochemical delamination method[2], which allowed the GNRs to preserve their structure, overall quality and orientation upon transfer. We performed polarized Raman in order to verify the quality of the transfer and the degree of orientation of the GNRs after the delamination process. Raman spectra after transfer showed intact RBLM, C-H and G modes indicating no significant degradation of GNR quality, figure 1(a). Polarized Raman of G and RBLM modes show that GNRs retain their orientation after transfer with maximum Raman intensity along the ribbon axis and minimum intensity perpendicular to it, figure 1(b). These process steps allowed us to fabricate for the first time short channel (L_{ch} ~2-5 nm) GNR devices using 5-AGNRs as channel material and graphene as electrodes. At room temperature, we demonstrate devices with a linear IV curve with currents in the nA regime. The metal-like behavior was observed for all 31 devices investigated at RT, figure 2(a). GNR devices measured at 13 K, showed single-electron transistor behavior, with addition energies of about 100 meV, figure 1(b).

References

[1] J. Cai *et al.*, Nature, 466, (2010), 470–473.

[2] B.V. Senkovskiy *et al*, Nano Letters, 17 (2017), 4029-4037.

Figures

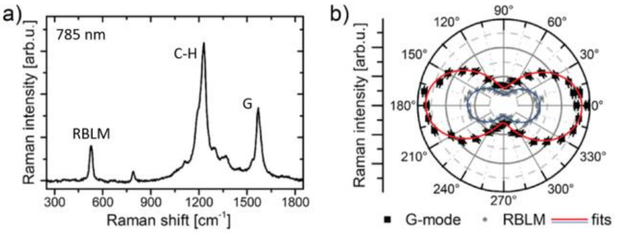

Figure 1: a) Raman spectrum of 5-AGNRs and (b) polar plot of Raman intensity as a function of polarization axis.

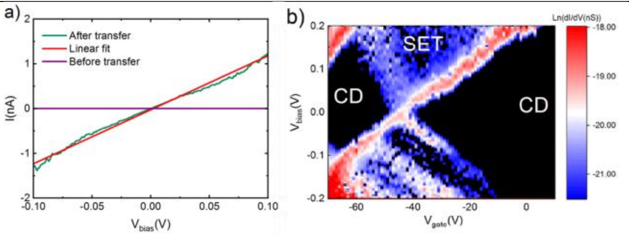

Figure 2: a) I-V curve at room temperature and b) stability diagrams of 5-AGNR bridging two graphene electrodes measured at 13K