Conductance mapping of large-area graphene: a new light on defects

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Abstract
We overview recent progress in analysing the conducting properties of large-area graphene by comparing several contact and non-contact mapping techniques. We combine three independent sheet conductance mapping techniques for detailed characterization of single layer graphene at different length-scales (λ), providing a consistent methodology for evaluating the electrical conductance and electrical defect distribution of large-area graphene[1]. Whereas terahertz time-domain spectroscopy (THz-TDS) maps the nanoscale conductance (λ ~ 10-100 nm) averaged over the beam spot size, spreading resistance probe (SRP) maps the sub-μm local conductance (λ ~ 100-1000 nm) and variable pitch micro four-point probe (M4PP) the micro-scale conductance (λ ~ 1-100 μm) (Fig. 1). The technique has been used successfully on up to 5 x 5 cm graphene samples.

These three inherently different sheet conductance mapping techniques have been applied for detailed characterization of centimeter-scale single layer graphene, grown by copper catalyzed CVD technique and transferred onto Si substrates coated with 90 nm SiO2. With more than 4000 individual measurement positions measured by each method we are able to conduct a statistical correlation analysis for the three techniques involved. We find a qualitative good agreement between the mean sheet conductance values measured with the three different techniques in areas of the graphene film that appear free from optically visible damage. However, in certain areas of the graphene film the measured sheet conductance, GS, is dependent on the measurement technique such that GS,M4PP < GS,SRP < GS,THz. Evidently this must be related to μm-scale and sub-μm-scale defects for which the M4PP and SRP methods are sensitive, respectively. This is supported by geometrical sample analysis possible with M4PP dual configuration measurements.

From the four-point resistance ratio R_A/R_B (where the R_A configuration is defined as I:V:V:I and R_B as I:V:I:V), it is possible to distinguish between samples, where the current transport is essentially 1D and 2D, respectively (Fig. 2). We show that for a continuous graphene film without defects or with defects, that have a spatial extend far smaller than the electrode pitch, the sample should behave as a 2D conductive film with R_A/R_B=1.265, whereas a highly damaged but still coherent film will give exactly R_A/R_B=1. This non-intuitive result is experimentally verified with great accuracy in our measurements. The discovery has the intriguing consequence that a statistical comparison of sheet conductance measured at different length-scales with the geometrical "foot-print" extracted from the RA/RB ratio allows for direct, parameter-free evaluation of both the defect density and the characteristic length scale of the defects.

Finally, we demonstrate that THz conductance mapping using a backgate highlights disconnected or damaged areas of CVD graphene, and discuss to which degree such optically derived conductance curves can be directly compared with electrical gate sweeps (Fig. 3).

References
[1] Buron, Jonas Christian Due; Petersen, Dirch Hjorth; Bøggild, Peter; Cooke, David G.; Hilke, Michael; Sun, Jie; Whiteway, Eric; Nielsen, Peter F.; Hansen, Ole; Yurgens, August; Jepsen, Peter Uhd, Nano Letters, 12 (2012), 5074

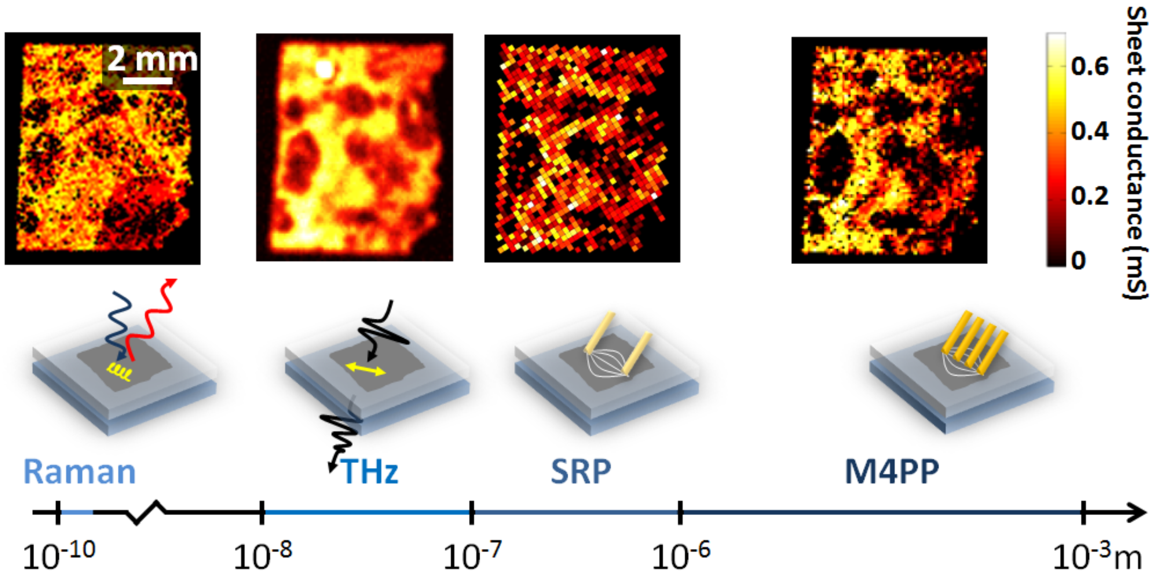

Figure 1. Combination of Raman spectroscopy, THz time-domain spectroscopy, spreading resistance measurements(SRP) and micro four point measurement(M4PP) yields information on conducting properties across scales ranging from sub-nanometer to millimetre scale.

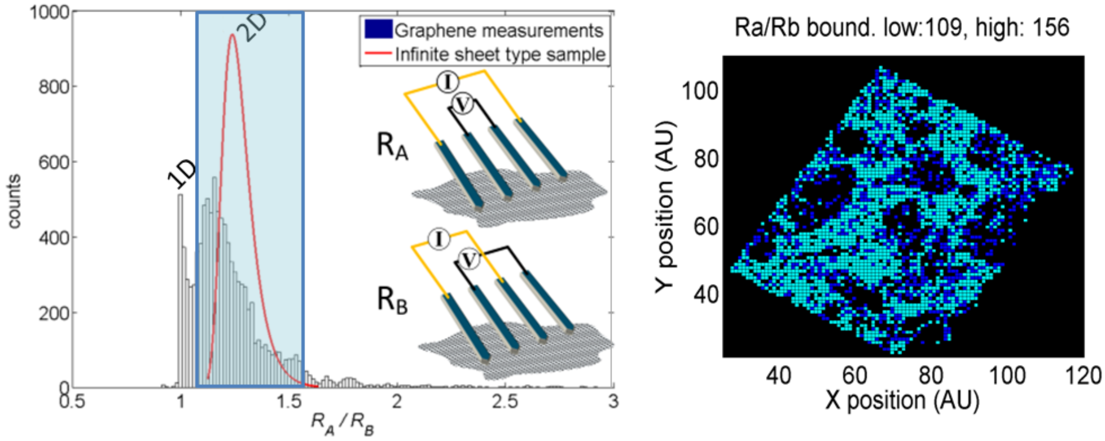

Figure 2. The ratio of resistances measured in A and B configuration is highly sensitive to the local integrity of the graphene sheet, with R_A/R_B = 1.26 corresponding to the limit of inifinite 2D graphene, and R_A/R_B = 1.00 corresponding to a 1D or 1D/2D dimensionality due to for instance cracks, rips, domain boundaries or other macroscale defects.

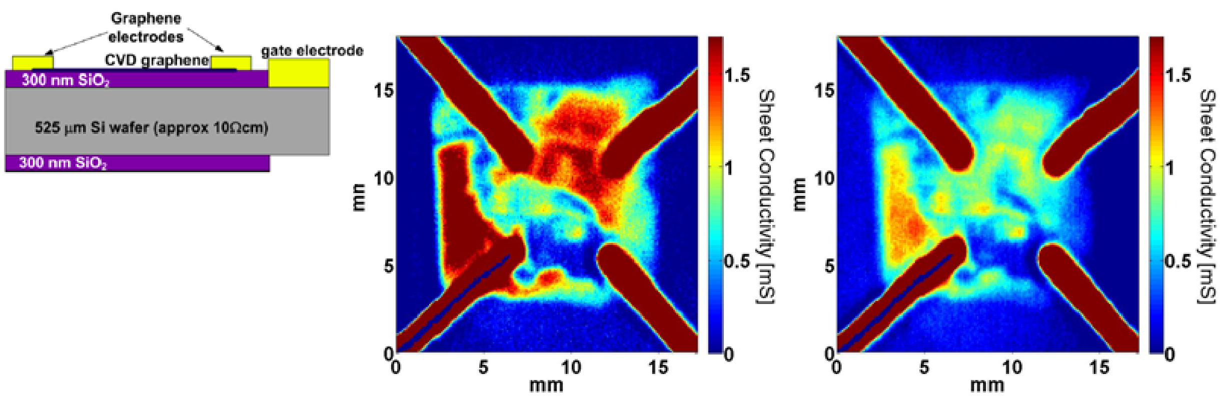

Figure 3. THz conductance mapping of a graphene sheet for different applied gate voltages using a moderately to low doped silicon substrate as a back gate, allows large-area, non-contact identification of connected/active and disconnected/inactive areas. The top contacts are present to allow direct comparison with conventional electrical conductance measurements.