Large-scale electrical characterization of graphene

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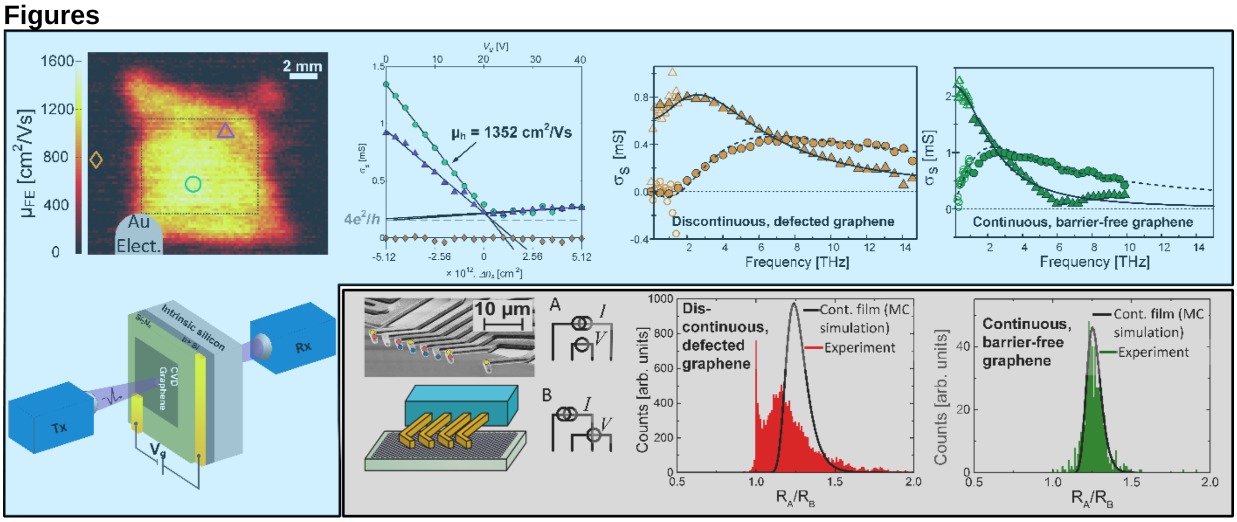
Abstract
There is a profound interest in the commercial adaptation of large-area graphene of high electrical quality for electronics and optoelectronics applications, including terahertz (THz) electronics and transparent, flexible, and durable electrodes for graphene-based touch-screens and solar cells. However promising, synthesized graphene shows large variations in quality, highlighting a need for electrical characterization on a large scale, for development of the material towards a position as a real alternative for electronic applications. In spite of very impressive advances in the available processes for large-scale synthesis, however, development of techniques targeting such electrical characterization of graphene on a large scale has not kept pace.
We have introduced micro four-point probe (M4PP) and terahertz time-domain spectroscopy[1], which are two non-invasive methods for characterization of the electrical properties of graphene, including sheet conductance[2], carrier mobility[3], sheet carrier density[3], Dirac point[3] and carrier scattering rate[1]. In addition to accurate and direct observation of fundamental transport properties as well as carrier dynamics at terahertz frequencies[1], we show that THz-TDS and M4PP are capable of rapid, non-invasive and reliable large-scale mapping of graphene that might be viewed as a vital requirement for industrial implementation of graphene.
Through back-gated THz-TDS carrier mobility mapping experiments[3], we demonstrate large-scale carrier mobility and carrier density mapping, and show that mm-scale variations in the sheet conductance CVD graphene is attributed primarily to variations in carrier mobility rather than the chemical doping level, which is highly homogeneous. We show how ultra-broadband THz-TDS can identify the characteristic carrier dynamics regimes of barrier free (Drude) and restrained (Drude-Smith) carriers in a sheet of graphene. We show that the presence of extended line defects can be identified by ultra-broadband THz-TDS as well as M4PP on the scale of nano- and micro-meter, respectively. Using this method we find that graphene synthesised on single crystal Cu(111) shows clear signs of being barrier free, which stands in contrast with our observations on graphene grown on copper foil.

References

1. Buron, J. D. *et al.*, Nano Lett. **14,** (2014) 6348–6355.
2. Buron, J. D. *et al.*, Nano Lett. **12,** (2012) 5074–5081.
3. Buron, J. D. *et al.*, in preparation. (2014).

Figures



Examples of THz-TDS and M4PP characterization of graphene. **(Blue)** Large-area field-effect mobility map of CVD graphene film. Gate-voltage dependence in 3 selected areas. Orange circles/triangles: THz conductance spectrum for discontinuous CVD graphene grown on poly-crystal Cu exhibits Drude-Smith behavior. Green circles/triangles: THz conductance spectrum for continuous CVD graphene grown on single crystal Cu(111) shows Drude behavior. Beneath: schematic of non-contact transmission THz-TDS measurement. **(gray)** Switched configuration M4PP can be used to evaluate graphene film continuity on the length scale of the electrode pitch. Red columns: R_A/R_B distribution of CVD graphene grown on poly-crystal Cu shows fingerprints of non-2D, non-continuous conduction. Green columns: R_A/R_B distribution of CVD graphene grown on single-crystal Cu shows fingerprints 2D continuous conduction