Low-temperature quantum transport in 2D materials

Starting from high quality CVD-grown single crystal graphene we fabricated both Hall-bars and Quantum Point Contacts which we extensively studied in the Quantum Hall (QH) regime showing full control over backscattering and equilibration of the topologically-protected edge states. Strain engineering was also explored as an alternative and original method to modify the electronic properties and induce quantizing pseudomagnetic fields. To this end, we pulled free-standing graphene membranes and studied strain using micro-Raman. Finally, we observe weak localization features in black Phosphorus from which information about elastic and inelastic scattering lengths is extracted. The anomalous temperature dependence of the inelastic scattering length is a signature of the in-plane crystalline anisotropy in black Phosphorus.

Quantum Hall effects offer a formidable playground for the investigation of quantum transport phenomena. Our low-temperature magneto-transport data show more than 12 flat and discernible half-integer quantum Hall plateaus in single-crystal CVD graphene samples on both the electron and hole sides of the Dirac point [1]. We furthermore demonstrate a buried split-gate architecture with this material. The control of the edge trajectories in these devices is demonstrated by observation of various fractional quantum resistances, as a result of a controllable inter-edge scattering. Our architecture is particularly promising and unique in view of the investigation of quantum transport via scanning probe microscopy, since graphene constitutes the topmost layer of the device [2].

The unique electronic properties of graphene can be strongly influenced by a mechanical deformation of its carbon lattice. For peculiar strain profiles, it is possible to induce an effect which is equivalent to a quantizing magnetic field having two opposite signs for the two Dirac cones. We demonstrate a novel method to obtain a custom strain profile by depositing graphene on a patterned SiN membrane and by applying a differential pressure load (see Fig. 2). We show in particular that a uniaxial deformation can be obtained for elliptical holes [3]. The strain induced on the graphene flake is studied by micro-Raman spectroscopy of the G and 2D peaks and based on a comparison with finite element models. Using simulations, we identify suitable architectures for the observation of pseudomagnetic fields.

Weak localization was observed in a black phosphorus field-effect transistor, see Fig. 3, in excellent agreement with the Hikami-Larkin-Nagaoka model, from which characteristic scattering lengths could be inferred. The temperature dependence of the phase coherence length $L\phi$ wa s found to decrease weaker than expected for two dimensions. Rather, the observed power law was found to be close to that observed previously in quasi-one-dimensional systems such as metallic nanowires and carbon nanotubes.

We attribute this more robust character of $L\phi$ to the highly anisotropic nature of the puckered honeycomb crystal structure of bP [4]. Ongoing work focuses on the functionalization of exfoliated bP [5].

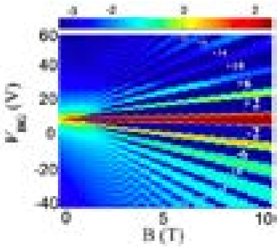

Fig. 1
Landau fan diagram, in which the longitudinal resistance R_{xx} across the split gate is plotted as a function of back gate voltage V_{BG} and magnetic field B. More than 12 Landau levels can be seen in this diagram, indicated by their respective index. Color scale gives $\log(R_{xx})$. Temperature T = 250 mK.

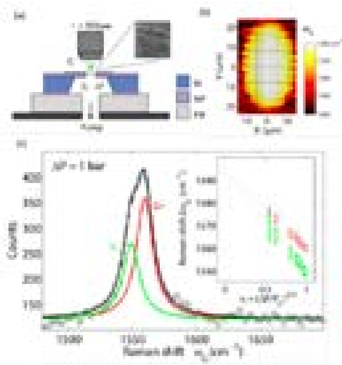

Fig. 2
Unaxially strained graphene. (a) A graphene flake deposited on a SiN membrane with an elliptic hole is subject to a differential pressure load DP. (b) Average strain is detected by measuring the local energy shift of the Raman peaks: the G peak shift is visible in the panel. (c) The presence of an anisotropic strain component induces a splitting of the two G+ and G– phonon modes.

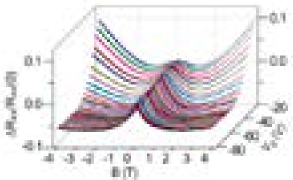

Fig. 3
Weak localization measurements. (a) The characteristic weak localization peak is observed in a plot of the normalized longitudinal resistance (R_{xx} (B) − R_{xx}(0))/R_{xx}(0) versus magnetic field B and gate voltage V_g at T = 0.26 K.

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