Quantum Transport along PN-Junctions in Ballistic Graphene

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Abstract

We report on our recent experiments in ballistic graphene pn-junctions. Ultraclean graphene is obtained either by suspension [1] or by encapsulation with h-BN [2]. The pn-junctions are formed by electrostatic gating using bottom and/or top gates. All devices show **Fabry-Perot oscillations** over the whole device size proofing the ballistic nature of electron transport [3]. Since in encapsulated garphene a superlattice can form, secondary Dirac points may appear. We first show that a Fabry-Perot cavity can also be formed by interfaces defined by these **satellite Dirac points** that mimic a pn-junctions [4]. We compare visibility and gate-defined cavity lengths in these "secondary" Fabry-Perot cavities.
Next, we will focus on transport in magnetic field. At a sufficiently large magnetic field, or small enough carrier density, discrete and localized Landau levels form in the bulk, whereas compressible chiral channels propagating along the edges of the graphene device appear. Due to the reversed chirality between the n and the p region, the edge states arriving from the n and p side at the p-n junction 'combine' to form a conducting channel along the pn-junction, connecting the lower and upper edge. Since the density-of-state goes through zero at the p-n junction, one only has to consider the lowest energy Landau levels. Since there are two channels that arrive from the n and p side to the pn-junction, say at the bottom edge, there are also two each leaving on the top edge. Along the pn-junction there are obviously then at most four channels. The maximum conductance from source to drain corresponds to the full transmission of the incoming populated channels and is therefore equal to 2e2/h. There have been contradicting observations recently. **Oscillations in conductance** along a pn-junction in magnetic field were assigned to the appearance of **snake-states**, which is a classical description of the cyclic motion of an electron wave package along the junction in magnetic field [5], or to **Mach-Zehnder like** interference [6,7]. The latter occurs naturally if the four-fold degenerate quantum channel along the pn-juctions is lifted in energy, e.g. due to electron-electron interaction and/or Zeeman energy, yielding four channels that are specially separated.

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What is quite remarkable in our experiment is that we observe *both* the Mach-Zehnder and "snake-state"-oscillations *simultaneously* on the same sample. Moreover, we observe a **third quantum transport phenomena**, also a sort of oscillation, which is very pronounced [8]. We see that the conductance between source and drain modulates with the *position* of the pn-junction, which can be moved by changing the gate voltages appropriately, by a large amount of order e2/h. We interpret this observation as a signature of **isospin polarization** at the edges. The two-fold degenerate edge state has a particular isospin configuration depending on the atomic structure of the edge. This isospin changes sign at the pn-junction on the same edge. Depending whether the top and bottom edge have the same or a different edge configuration the conductance will be large (maximal) or small (zero, if the two isospin states are orthogonal). The experimental observation is supported by quantum-transport calculations. While the explanations for the three (different) phenomena seem plausible, it would still be good, if one could describe all on the same footing with one single theory.

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