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Fabry–Pérot resonances in narrowly separated p-n interfaces in hBN/graphene/hBN with quantum point contact

Among various unique features in two-dimensional (2D) electrons in graphene, ballistic transport is of great interest for fundamental study in electronic quantum optics based on quantum interference between electron waves. Ballistic conduction of electrons in graphene is enhanced by suppressed backscattering, which can be further improved by sandwiching graphene between hexagonal boron nitride (hBN) sheets. More interesting phenomena in such ballistic conduction emerge when the 2D electrons are under a magnetic field. With an increased magnetic field perpendicular to the 2D sheet, an electron trajectory will be bended by Lorenz force to form a closed cyclotron orbit, and it evolves into quantum Hall regime in which carrier conduction is governed by dissipationless edge channels. For example, as the perpendicular magnetic field increases in an n-p-n narrow cavity, carrier conductance oscillations of the Fabry–Pérot interference regime will exhibit a crossover to Shubnikov-de Haas oscillations of the quantum Hall regime [1]. It is expected that such crossover can be strongly affected by a nanometer size structure of the cavity which is comparable to the cyclotron radius. In this study, we report on the observation of Fabry–Pérot interference and its crossover to the quantum Hall regime of ballistic electrons in a single layer graphene sheet with a gate-defined quantum point contact (QPC).

In our fabricated device, a single layer graphene sheet was sandwiched between high-quality hBN sheets, and it was attached with narrow top-gate electrodes with a split-gate structure at the center. The carrier density in graphene was controlled electrostatically with both top and back gates independently [2]. In the cryogenic conditions, longitudinal differential resistance, R_L, was measured across the top-gated region by a four-terminal lock-in measurement method. Figure 1 shows the obtained B-V_{TG} mapping of dR_L/dV_{TG} at V_{BG} = 1.2 V at a temperature of 6 K, where V_{TG} and V_{BG} are the top and back gate biases, respectively. In the low magnetic fields ($|B|$ < ~0.2 T), resistance exhibited Fabry–Pérot oscillations due to the interference in n-p-n cavities formed by positive V_{BG} and negative V_{TG}, while the pair of p-n junctions act as semi-reflective mirrors. Although the QPC structure overlaps with the resonant cavity, Fabry–Pérot resonance was still observed, guaranteeing a collimating effect on ballistically transmitted carriers. Here, the phase of the resonance oscillation shifted to the left as an increase in $|B|$, indicating that an additional Berry phase of π was added to the electrons trajectories when it surrounded the degeneracy point of the band structure, $k_x = k_y = 0$ [1]. As $|B|$ exceeded 0.2 V, a crossover from the Fabry–Pérot regime to the quantum Hall regime was observed [3], which is different from that observed in a rectangular n-p-n narrow cavity without QPC structure [1]. As indicated by a dashed yellow line in Fig.1, we found parabola-shaped stripes between Fabry–Pérot and quantum Hall regimes, which are a unique feature of QPC structure with a size comparable to the cyclotron radius. When the electrons cyclotron radius becomes comparable to the cavity size around the QPC, the basic set-up undergoes a crossover to the edge channel transport of the quantum Hall regime through ‘snake trajectories’ [3]. Obtained results could provide us a key to understand the effects of magnetic fields on the ballistic electron transport in graphene for future electronic quantum optics devices.

References

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Figure

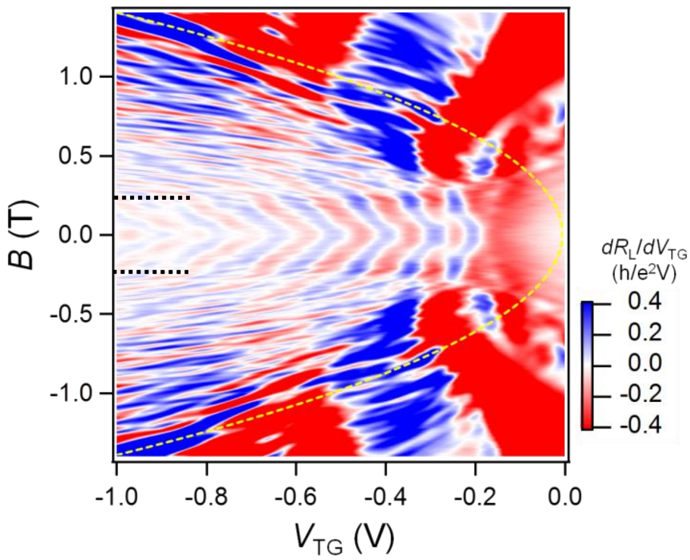

Figure 1: A B-V_{TG} mapping of dR_L/dV_{TG} at V_{BG} = 1.2 V and at 6 K in an hBN/graphene/hBN device with a QPC. Carrier density in whole graphene device was controlled by a back gate bias, and p-n junctions were formed by local control of carrier density by top split gates. Fabry–Pérot oscillations due to the interference in n-p-n cavities were observed at $|B| < \sim 0.2$ T, and they collapsed under higher magnetic fields.