Quantum Oscillations in Black Phosphorus Two-dimensional Electron Gas

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Introduction

Black phosphorus has recently emerged as a new member in the family of two-dimensional (2D) atomic crystals[1,2]. It is a semiconductor with a tunable bandgap and high carrier mobility – material properties that are important for potential opto-electronic and high-speed device applications.

Experimental

In this work, we achieve a record-high carrier mobility in black phosphorus by placing it on hexagonal boron nitride (h-BN) substrate (Fig. 1a). 2D electron and hole gas is induced at the black phosphorus/h-BN interface by the gate electric field. The exceptional mobility of the 2D electron gas created at the interface allows us to observe quantum oscillations for the first time in this material (Fig. 1b and Fig. 1c). The transport data was taken at Cell 9 in NHMFL.

Results and Discussion

We extract crucial information about the black phosphorus 2D electron and hole gas from the observed quantum oscillations. Specifically, we obtain a hole effective mass of $0.34m_0$ and an electron effective mass of $0.47m_0$, which are larger than the values measured in the bulk[3], possibly due to quantum confinement. The quantum life time of the carrier is determined to be ~0.1ps.

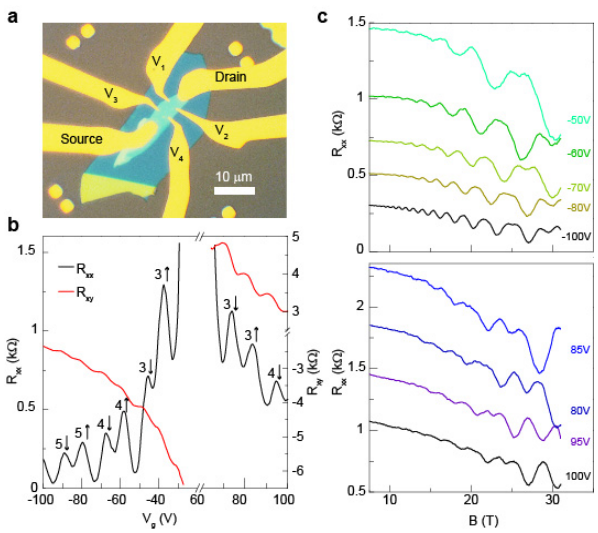

Figure 1 a, Optical image of our black phosphorus device with h-BN substrate. **b,** R_{xx} (black) and R_{xy} (red) measured as a function of V_g with magnetic field fixed at B = 31 T. LL index of each peak is indicated in the figure. Spin degeneracy is lifted at each LL and the arrows indicate the spin-up and spin-down LLs. **c,** R_{xx} as a function of magnetic field measured at varying gate voltages. SdH oscillations are observed for both holes (upper panel) and electrons (lower panel). Temperature is fixed at 0.3 K during the measurement.

Conclusions

Our experimental results introduce black phosphorus 2D electron gases to the elite family of high quality electron systems, and open the door to future research on quantum transport in black phosphorus.

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