**Quantum Hall Effect in Black Phosphorus Two-dimensional Electron System**

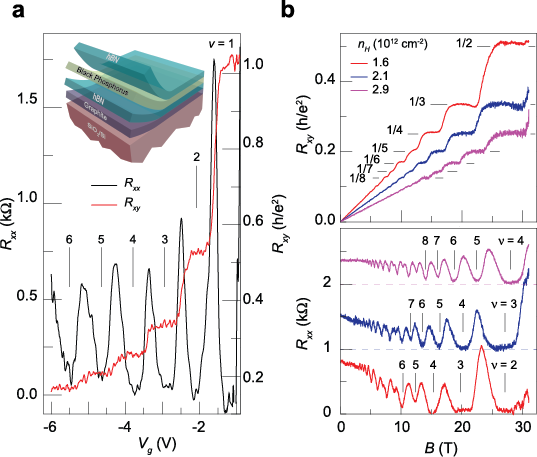
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**Introduction**

Development of new, high quality functional materials has been at the forefront of condensed matter research. The recent advent of two-dimensional black phosphorus has greatly enriched the material base of two-dimensional electron systems (2DES)1-3. Here, we reach a milestone in black phosphorus research – the observation of integer quantum Hall (QH) effect in high quality black phosphorus 2DES.

**Experimental**

We achieve high quality by embedding the black phosphorus 2DES in a van der Waals heterostructure close to a graphite back gate; the graphite gate screens the impurity potential in the 2DES, and brings the carrier Hall mobility up to 6000 cm2/Vs. The exceptional mobility enabled us, for the first time, to observe QH effect, and to gain important information on the energetics of the spin-split Landau levels in black phosphorus. The transport data was taken at Cell 9 and Cell 15 in NHMFL.

**Results and Discussion**

The figure on the right displays the magnetoresistance (Rxx) and Hall resistance (Rxy) measured in high magnetic field at low temperatures. Panel **a** shows Rxx (black) and Rxy (red) measured as a function of Vg with magnetic field fixed at B = 31 T. Filling factor of each QH state is indicated in the figure. Inset: Schematic three-dimensional view of the device heterostructure. Panel **b**: Hall resistance (upper panel) and magnetoresistance (lower panel) as a function of magnetic field measured at varying hole doping levels (Vg <0). All data were taken at T=300 mK. Additional angle-dependent magneto-transport measurements indicate that Zeeman energy is a significant fraction of the cyclotron energy in black phosphorus 2DHG.

**Conclusions**

We have achieved exceptionally high carrier mobility in black phosphorus 2DHG, which enabled us, for the first time, to observe the integer QH effect in black phosphorus. The large Zeeman energy relative to cyclotron energy, coupled with black phosphorus’s anisotropic electronic structure, may lead to exotic quantum states in the fractional QH regime.

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**References**

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