Quantum Transport in Black Phosphorus Two-dimensional Electron Systems

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Introduction

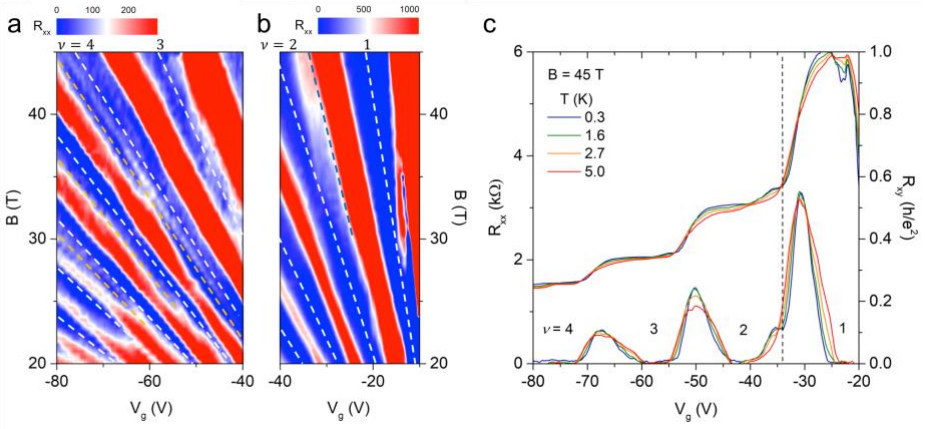
The recent advent of two-dimensional black phosphorus (BP) has greatly enriched the materials base of two-dimensional electron systems (2DESs)[1-3]. We have previously observed the quantum Hall effect (QHE) in BP hole gas for the first time[4]. Our results, obtained at the NHMFL, set the stage for further study on quantum transport in BP 2DES in the ultrahigh mobility regime. In particular, BP's heavy carrier mass and anisotropic electronic structure may lead to exotic quantum phenomena beyond the integer quantum Hall effect.

Experimental

We achieved high mobility in BP 2DES by constructing a BP/hBN/graphite van der Waals heterostructure. (Here hBN refers to hexagonal boron nitride.) The graphite serves as a back gate which also screens impurity potential in the 2DES. This brings the hole carrier Hall mobility up to ~ 9000 cm^2/Vs. The transport measurement was performed in high magnetic fields in Cell 15 at the NHMFL.

Results and Discussion

In those high mobility BP specimens, we observed new states beyond integer quantum Hall effect in BP 2DES. Figures a and b display the magnetoresistance (R_{xx}) measured as a function of gate voltage and magnetic fields (up to 45 T). Integer quantum Hall states are marked by white dashed lines, and new states at fractional filling factors are marked by orange dashed lines (Figure a) and green dashed lines (Figure b). Temperature dependent measurement (Figure c) indicates the fractional state between ν=1 and ν=2 has an energy scale of approximately 5 K at 45 T.



Conclusions

These observations, along with our previous results obtained at the NHMFL, indicate the formation of a striped charge density wave (CDW) phase in BP 2DESs. Moreover, a new state emerges between ν=1 and ν=2, which does not seems to fit the CDW description; it may instead be a fractional quantum Hall state. More experiments are needed to clarify the nature of this new state.

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