Broken-Symmetry Landau Levels in Bilayer Graphene and Their Impact on the Quantum Valley Hall Kink States

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Introduction

The E=0 Landau levels (LLs) of bilayer graphene exhibits complex symmetry breaking and transitions between ground states of different orders driven by external electric and magnetic fields. The external electric field controls the splitting between the K and K' valleys and the splitting between the N=0 and 1 orbitals. The external magnetic field controls the Coulomb interaction strength and the enhanced Zeeman splitting. The interplay of the two results in a complex LL diagram, which we have constructed empirically combining our own measurements and previous studies. The splitting of the bulk LLs also leads to the spatial separation of the quantum valley Hall kink states at the line junction of two oppositely gated bilayer graphene regions and quantized fractional transmission coefficients.

Experimental

We completed two studies using both the superconducting (18T) and the resistive magnets (31T) of the DC field facility in Tallahassee. Two manuscripts are currently under review [1, 2].

Results and Discussion

In Ref. [1], we measured the magnetic field dependence of the displacement electric fields D^*_h and D^*_l at which the gap of the ν=0 state in bilayer graphene closes (**Fig. 1(a)**) and used the difference between D^*_h and D^*_l to obtain a quantitative expression of the N=0 and 1 orbital splitting E_{10} **(Fig. 1(b))**. The *D*-*B* relation, together with the ν=1, 2, 3 gap energies, allowed us to derive an empirical Landau level diagram as a function of both *D* and *B*. An example at *B*=31 T is shown in **Fig. 1(c)**. This diagram reproduces experimentally observed LL filling sequences. In Ref. [2], we demonstrated the guided transmission of the quantum valley Hall kink states in a four-terminal cross geometry. Quantized transmission coefficients at ¼, ½, and ¾ are observed at high fields (**Fig. 1(d)**) and attributed to the energy and spatial separation of the valley Hall kink modes caused by the splitting of the bulk bilayer graphene LLs.

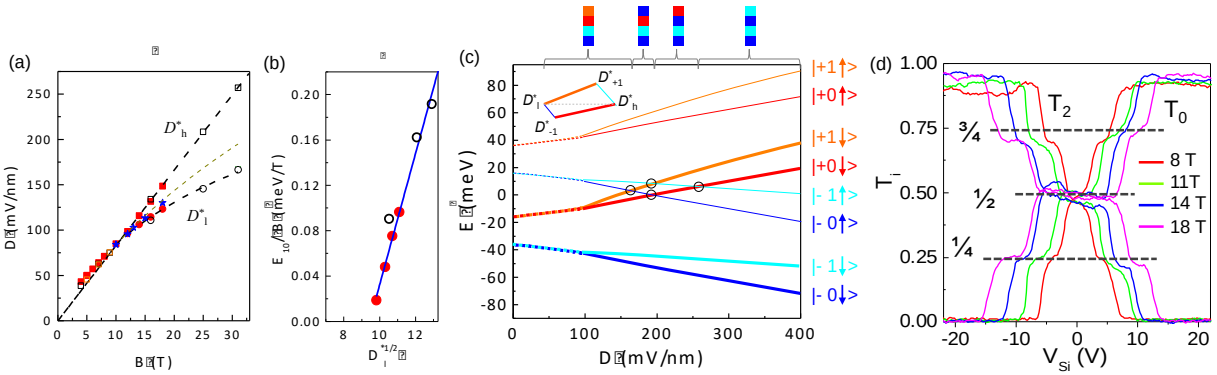

Fig.1 (a) The coincidence electric fields D^*_h and D^*_l of the ν= 0 (other symbols) and the ν=-1 (blue stars) states in bilayer graphene. (b) Orbital energy splitting E_{10} / *B* extracted from data in (a). The blue line is a fit. (c) The D-dependence of the empirical LL diagram at B=31T. Adapted from Ref. [1]. (d) Measured current transmission coefficients in a cross device of quantum valley Hall kink states. The fractional plateaus developed at high field originate from the well-resolved LLs of the E=0 octet in the bulk. Adapted from Ref. [2].

Conclusions

A quantitative Landau level diagram of the E=0 octet of bilayer graphene is obtained.

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References

[1] J. Li *et al.*, arXiv:1708.03644v1 (2017).
[2] J. Li *et al.*, arXiv:1708.02311v1 (2017).