Entropy Spectroscopy of a Bilayer Graphene Quantum Dot

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We measure the entropy change of a bilayer graphene quantum dot for single and two carrier occupation and as a function of magnetic field. The entropy is derived from the measured charge occupancy signal using a capacitively coupled detector[1] while modulating the temperature of one of the leads. This procedure was pioneered for gallium arsenide quantum dots by Hartmann et al[2] and we have adapted this experimental technique to graphene quantum circuits.

For single carrier occupancy at zero magnetic field we find a degeneracy of 2 (entropy of $k_{\mathrm{B}} \ln(2)$), which is consistent with recent findings that the spin/valley-quadruplet is split into two doublets because of intrinsic spin-orbit interaction.

The entropy evolution in magnetic field for the single-to-two carrier transition is shown in Fig. 1. At zero magnetic field the entropy change is $k_{\mathrm{B}} \ln(1/2)$, revealing an unanticipated, non-degenerate two-carrier ground state related to the splitting of the spin-triplet state. At moderate magnetic fields below $200\,\mathrm{mT}$ the entropy change is zero as all degeneracies of the quantum states are lifted. However, upon further increasing the magnetic field, an entropy peak of $k_{\mathrm{B}} \ln(2)$ is observed, in agreement with an expected ground state crossing caused by the magnetic field dependence of the valley states present in bilayer graphene.

This methodology shows that graphene quantum circuits, including single and double dots, charge sensors and local heating constrictions have advanced to enable investigations of entropy changes in strongly correlated electronic quantum states, such as Kondo systems[3].

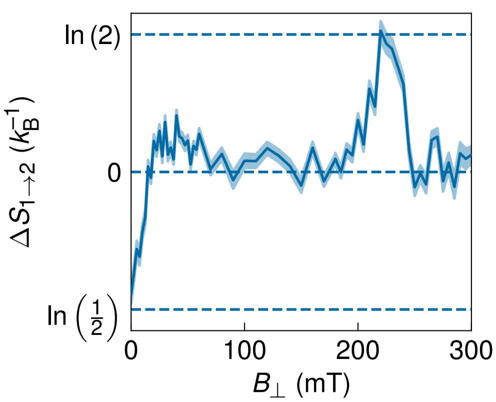

Fig. 1. Entropy change as a function of perpendicular magnetic field associated with the single-to-two carrier transition.

References

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