Charge-tunable quantum dots in monolayer WSe_2

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Gate-tunable tunnel coupling between a semiconductor quantum dot (QD) and a nearby Fermi sea has underpinned many advances in spintronics and solid-state quantum optics. Due to Coulomb blockade, such devices enable direct control over the quantum dot charge state (loading electrons or holes one at a time) [1].

In this work, we present single quantum dots in an atomically thin semiconductor that exhibit Coulomb blockade. The inset of Fig. 1 (a) shows a sketch of our device. A monolayer of WSe_2 is embedded in a heterostructure that allows a gate-tunable tunnel interaction between the quantum dots in WSe_2 and the Fermi sea in the few-layer graphene contact. Figure 1(a) shows the measured gate voltage (V_g)-dependent photoluminescence of a typical quantum dot in our device at 4 K. At $V_g = 0$, a neutral exciton with ~ 830 μeV fine-structure splitting is observed. At Vg ~ - 9V, a second electron tunnels into the QD, creating a negatively charged exciton (X^{1-}) with 25 meV binding energy. At $V_g > 10$V, the positively charged exciton X^{1+} is observed with 7 meV binding energy. Noticeably, only one spectral line is observed for the charged excitons as the electron-hole exchange interaction is turned off. With an applied magnetic field in Faraday geometry, the emission of the charged exciton species Zeeman splits into two lines. Figure 1 (b) shows the energy splitting of the X^{1-}, X^0 and X^{1+} as a function of the magnetic field, with each transition showing nearly identical g-factor values, as expected for semiconductor QDs.

Further, we observe signatures of coherent tunnel coupling between the QD and the nearby Fermi sea [2,3]. The smooth transition between the neutral and charged excitons signifies the existence of hybrid excitons resulting from the strong tunnel interaction between the QD and Fermi sea. Additionally, strong bending of the plateau edges is observed (e.g. the X^0 edges lower in energy due to the binding of the QD exciton and the Fermi sea when they are near resonance). Finally, strongly asymmetric lineshapes are observed in regions of strong tunnel coupling (e.g. the X^{1-} lineshape compared to the X^0 lineshape in the centre of the plateau).

In summary, we demonstrate Coulomb blockade of WSe_2 quantum dots in a charge tunable device. Magneto-optical spectroscopy of the positively charged, neutral, and negatively charged excitons reveals the nature of the WSe_2 quantum emitters to be semiconductor quantum dots rather than crystal defects. Further, due to the strong tunnel interaction between the quantum dot and Fermi sea, we observe remarkably strong Kondo-like many-body interactions between the localized states and the continuum of electron states. These results show that next generation 2D heterostructure devices offer the potential to further investigate and engineer either isolated single spins or strongly coupled many-body states in a two-dimensional platform.

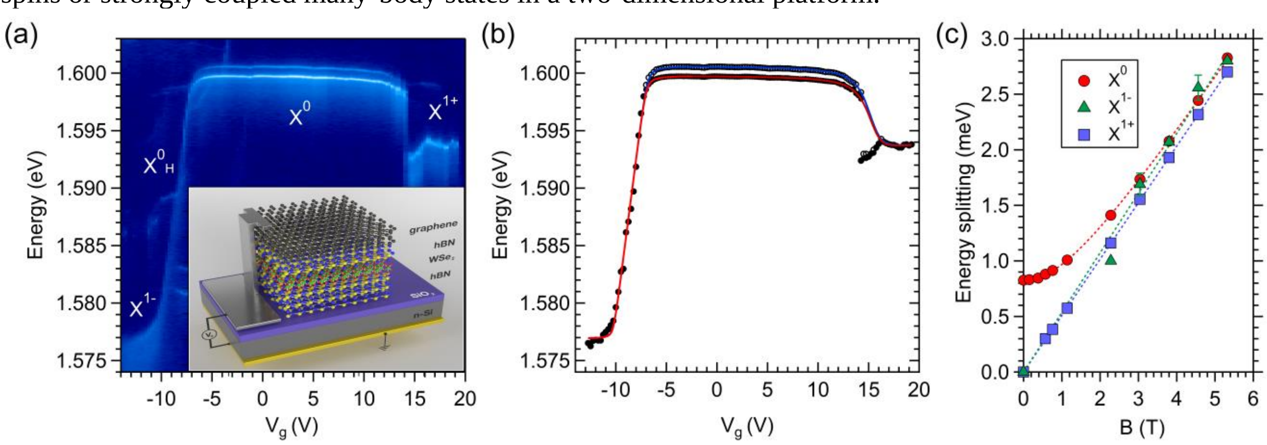

Figure 1. (a) Voltage-dependent PL of a QD in WSe_2. The inset shows a sketch of the charge-tunable device. (b) Magnetic field dependence of the fine-structure-split X^0 doublet and the X^{1-} and X^{1+} Zeeman splittings, with g-factors of 8.7 ± 0.1, 9.3 ± 0.1 and 8.8 ± 0.1, respectively.

References

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