Quantum Oscillations in Two-Dimensional Transition Metal Dichalcogenide Heterostructures

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Introduction

Atomically thin two-dimensional (2D) transition metal dichalcogenides (TMDCs), materials such as MoS_2 and WSe_2, and their heterostructures have attracted great interest for realization of advanced application devices. Monolayer TMDCs have broken inversion symmetry and strong spin-orbit coupling, thus 2D TMDC heterostructures could serve as an important platform for realization of unique quantum systems, and manipulation of spin-valley degree of freedom [1,2]. So far, large contact resistance and low electronic mobility of TMDC heterostructures has hampered efforts towards the observation of exotic quantum transport. To reduce extrinsic scattering effects and contact resistance, we developed a TMDC heterostructure platform where TMDCs such as MoS_2 and WSe_2 layers are fully encapsulated by hexagonal boron nitride (hBN) with multi-terminal graphene electrodes.

Experimental

Measurements conducted at the NHMFL using a 31T magnet with ^{3}He cryostat system (Cell 9) exhibited a dramatic improvment of Hall mobility reaching ~ 10,000 cm^2/Vs for few-layer MoS_2 and the first observation of Shubnikov-de Haas oscillation in CVD monolayer and few-layer MoS_2 heterostructures under high magnetic field at low temperature (300 mK) .

Results and Discussion

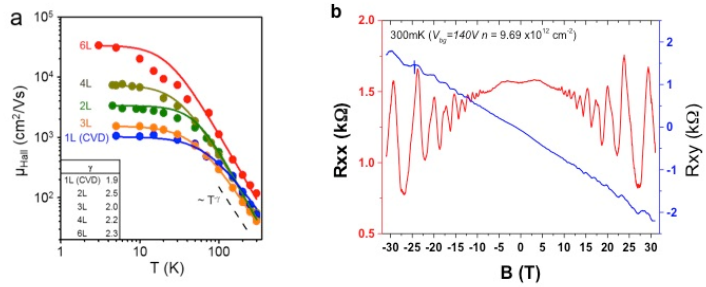

Fig. 1 a. Hall mobility of hBN encapsulated MoS2 devices. b, First observation of Shubnikov-de Haas oscillation in CVD monolayer MoS_2

From the ultrahigh mobility of MoS_2 heterostructure, we can observe quantum oscillations, which include spin-splitting by Zeeman effect under high magnetic field, and crossover of multiple sub-band in few-layer MoS_2 by electrostatic doping. Furthermore, we estimate the effective mass, scattering times and charge carrier concentrations of MoS_2 from Shubnikov-de Haas oscillations results. These results support the use of hBN encapsulation with ultraclean transfer method for suppression of most extrinsic scattering effects and graphene electrodes for Ohmic contact in order to characterize the intrinsic transport of MoS_2 heterostructures.

Conclusions

2D TMDC heterostructures with ultra high mobility could serve as a new platform to reveal characteristics of coherent mesoscopic systems such as quantum point contacts, quantum dots, and electron interferometers. We can fabricate a seemingly infinite number of artificial semiconductor interfaces by stacking various 2D crystal materials without traditional semiconductor growth. In particular, 2D TMDC heterostructures in ultra high magnetic fields will allow for the observation of new emergent quantum behavior such as unconventional quantum spin-valley Hall effect in 2D crystal materials

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References

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