Electronic and excitonic properties of semiconductor bilayer moiré system revealed by optical spectroscopy

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The recent discovery of many-body physics such as strongly correlated electrons, superconductivity and magnetism in precisely twist angle-controlled bilayer graphene at a magic angle revived enormous interest on moiré lattice system. Many-body physics in bilayer moiré system is not limited to graphene, but rather robustly appears in 2D semiconductor materials such as transition metal dichalcogenides (TMDs). Monolayer semiconductor TMDs have conduction and valence bands with relatively large effective mass which enhances the influence of Coulomb interactions, also resulting in formation of strongly bound excitons with optical excitations. In twisted bilayer semiconductor TMDs, the superlattice effect due to the formation of moiré lattice further enhances the influence of Coulomb interaction for electrons and expected to show many-body electronic phases. On the other hand, it has been a long-standing issue that semiconductor TMDs have poor electrical contact properties due to the formation of Schottky barriers, which has been hindering the observation of those many-body electronic phases in moiré system via transport measurement. Instead, we performed optical microscopic spectroscopy experiments of a bilayer TMD moiré system which revealed many-body electronic phase, quantum coupled excitonic states, and novel quantum mixture of exciton – hole states.

Here we studied a twisted bilayer $MoSe_2$ system with monolayer hBN tunnel barrier (Figure 1). The combination of the top and bottom gates allows to control the chemical potential and the perpendicular electric field independently. The energy shifts of excitonic resonances (exciton polarons) probe the carrier densities of the top and bottom layers independently, which revealed the formation of moiré sub bands in the system. By changing the energy detuning between layers via control of the perpendicular electric field, we observed an abrupt charge transfer at $\nu = 1$ (1 electron per moiré lattice) and a stabilized charge transfer plateau at $\nu = 2$ around zero detuning point, which evidences the existence of strongly correlated electrons [1]. We further observed the existence of charge order at these fillings from the Umklapp scattering of excitons [2]. Last but not least, we figured out that the tunnel coupling of holes through the monolayer hBN barrier results in formation of hybrid exciton states [1] and electric field-controlled exciton – hole Feshbach resonances [3].

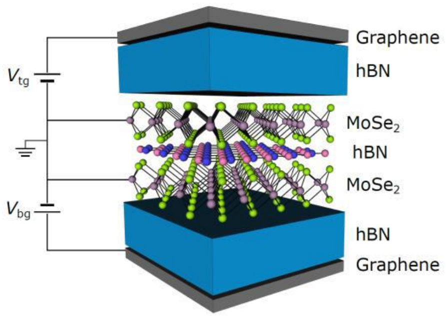

Figure 1: Schematic sketch of $MoSe_2$ / hBN / $MoSe_2$ heterostructure

References

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