Signatures of correlated electrons in a moiré superlattice in exciton spectrum

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2D material moiré heterostructure constitute a novel platform to study many body physics of electrons and excitons. Transport study of twisted bilayer graphene revealed rich exotic phase of electrons including Mott insulator state, superconductivity, strange metal, and ferromagnetism [1, 2]. On the other hand, optical spectroscopy revealed the effect of moiré lattice potential on excitons in transition metal dichalcogenide (TMD) heterostructure [3], but a direct evidence for the correlated phase of electrons has been elusive.

In this talk, I will present resonant optical measurements on homo-bilayer TMD moiré heterostructure, and report the observation of strongly correlated incompressible electronic states as well as hybrid dipolar excitons [4]. We utilized a boron nitride (hBN) encapsulated $MoSe_2$ / hBN (1L) / $MoSe_2$ heterostructure which has top and bottom gate (Fig. 1a). Using top and bottom gate, we can control the chemical potential and the electric field (band alignment) independently. Tightly bound excitons in TMD interact with Fermi sea carriers by forming exciton-polaron [5], and we utilized the energy shift of exciton-polaron resonance to detect layer resolved charge configuration by optical means. In low electron density regime, we found periodic chemical potential dependence of carrier filling behavior indicating existence of moiré subband structure, and estimated that the twist angle of $MoSe_2$ layers is about 0.8 degree (Fig. 1b). By analyzing interlayer charge transfer behavior between top and bottom $MoSe_2$ while tuning electric field, we figured out abrupt interlayer charge transfer happens at specific filling around $\nu = 0.5$ (1 electron / moiré unit cell), evidencing the emergence of strongly correlated incompressible electronic state (Fig. 1c). We also observe interlayer exciton hybridizing with intralayer exciton in neutral regime, and the fine energy splitting of interlayer exciton is consistent with moiré potential induced Umklapp scattering.

This highly tunable twisted $MoSe_2$ homo bilayer system separated by a monolayer hBN barrier with weak moiré potential, provides a promising platform for investigating strongly correlated Mott-Wigner physics as well as hybrid excitons. In particular, this structure could be used to study Bose-Fermi mixture constituting of strongly correlated electrons interacting with dense excitons and polaritons, and is expected to provide rich playground for many body physics.

References

[1] Y. Cao et al., Nature, **556** 43 (2018).
[2] X. Lu et al., Nature, **574** 653 (2019).
[3] K. L. Seyler et al., Nature, **567** 66 (2019)., K. Tran et al., Nature, **567** 71 (2019)., C. Jin et al., Nature, **567** 76 (2019)., E. M. Alexeev et al., Nature, **567** 81 (2019).
[4] Y. Shimazaki et al., Nature, **580** 472 (2020).
[5] M. Sidler et al., Nature Physics, **13** 255 (2017).

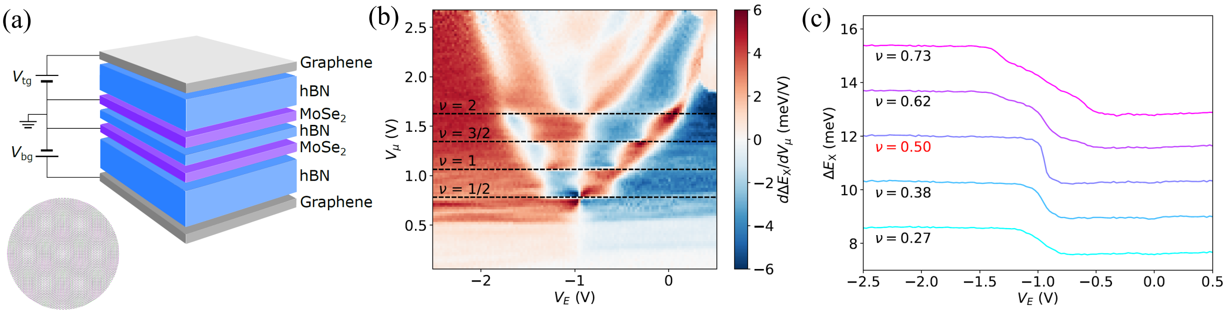

Figure 1. (a) Schematic sketch of the device structure. (b) Layer contrasted carrier filling behavior monitored by repulsive exciton-polaron resonance energy shift. V_E and V_μ correspond to the axes of electric field and chemical potential. (c) Difference of exciton-polaron resonance energy between top and bottom layers, highlighting charge imbalance between top and bottom layers.