Electronic and Optoelectronic Physics in the van der Waals Heterojunctions

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Recent advances of van der Waals (vdW) materials and their heterostructures provide a new opportunity to realize atomically sharp interfaces in the ultimate quantum limit. By assembling atomic layers of vdW materials, such as hexa boronitride, transition metal chalcogenide and graphene, we can construct novel quantum structures. Unlike conventional semiconductor heterostructures, charge transport of the devices is found to critically depend on the interlayer charge transport, electron-hole recombination process mediated by tunneling across the interface. We demonstrate the enhanced electronic optoelectronic performances in the vdW heterostructures, tuned by applying gate voltages, suggesting that these a few atom thick interfaces may provide a fundamental platform to realize novel physical phenomena, such as cross-Andreev reflection across the quantum Hall edges states [1] and interlayer magneto-exciton condensation [2]. In addition, spatially confined quantum structures in semiconducting transition metal dichalcogenide (TMDC) can offer unique valley-spin features, holding the promises for novel mesoscopic systems, such as valley-spin qubits. The gate-defined quantum structures formed in atomically thin TMDC heterostructures exhibit quantum transport phenomena and optoelectronic processes [3]. We also report the fabrication of the gate-defined TMDC heterostructures. Using an optical excitation, we generate excitons with the electron and the hole each residing in the two different TMDs interlayer excitons (IE) as shown in Fig. 1. Thus, IEs have a dipole moment oriented out-of-plane and are repulsive in nature, because of the Coulomb interaction. With increasing excitation power, we create a large density of IEs ($5x10^{11}$ cm-2) and observe long diffusion ~ 20μm even at elevated temperatures (T = 60K). A large density of IEs is important for novel optoelectronic devices such as IE condensates

References

[1] G. H. Lee *et al*., Nature Physics, **13** (2017) 693-698

[2] X. Liu *et al*., Nature Physics, **13** (2017) 746-750

[3] K. Wang *et al*., Nature Nano, **13** (2018) 128-132

Figures

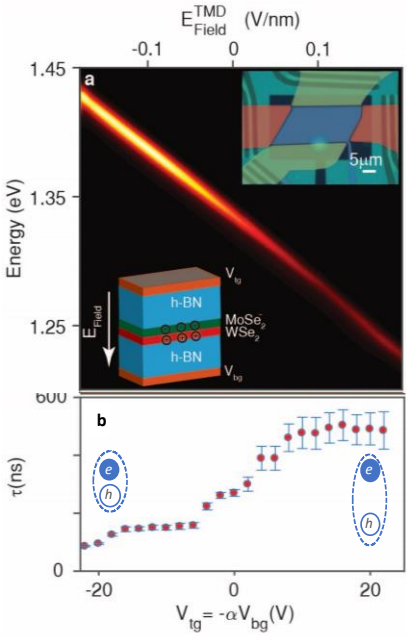

Figure 1: (a) Electric field dependence of the interlayer exciton photoluminescence (PL). Upper right inset: optical image of a representative device with the top-gates false colored. Lower left insets (a) - (b): schematics of the heterostructure cross section under light illumination, showing electrons (holes) accumulate on the MoSe2 (WSe2) layers. (b) Interlayer exciton lifetime versus electric fields.