Degenerate many-body states and multi-valley physics of excitons in vdW hetero-bilayers

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Increasing the interaction strength between quasiparticles can cause strong correlations, collective phenomena and transition to emergent quantum phases. Atomistic van der Waals heterostacks are ideal systems for high-temperature exciton condensation because of large exciton binding energies, an interfacial dipole moment, long lifetimes [1,2]. Light emission and electron energy-loss spectroscopy showed first evidence of excitonic many-body states in such two-dimensional materials [3,4]. Pure optical studies, the most obvious way to access the phase diagram of photogenerated excitons have been elusive. We observe several criticalities in photogenerated exciton ensembles hosted in $MoSe_2$–WSe_2 heterostacks with respect to photoluminescence intensity, linewidth, and temporal coherence pointing towards the transition to a coherent many-body quantum state, consistent with the predicted critical degeneracy temperature. For this state, the estimated occupation is approximately 100% and the phenomena survive above 10 Kelvin [5]. We demonstrate furthermore electric field control of layer index, orbital character, lifetime, and emission energy of indirect excitons in MoS_2 - WS_2 heterobilayers embedded in an vdW field-effect structure due to valley selective hybridization and multi valley physics [2,5]

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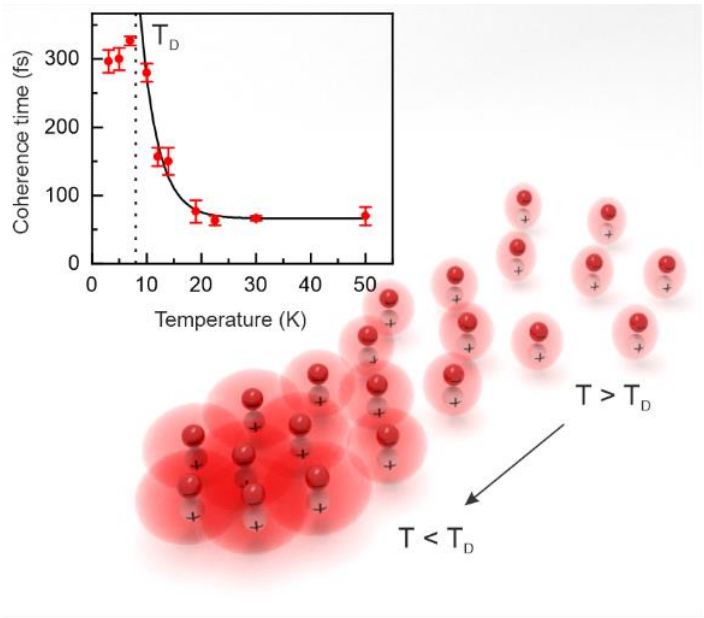

Fig. 1 Below the degeneracy temperature T_D, a many-body state emanates of interacting excitons, giving rise to enhanced coherence time [2].

References

[1] B. Miller, et al. "Long-lived direct and indirect interlayer excitons in van der Waals heterostructures," Nano Letters **17**, 5229 (2017). (2017).
[2] J. Kiemle, et al. "Control of the orbital character of indirect excitons in MoS_2/WS_2 heterobilayers," Phys. Rev. B 101, 121404(R) (2020)
[3] A. Kogar, et al. "Signatures of exciton condensation in a transition metal dichalcogenide, Science 358, 1314 (2017).
[4] Z.Wang, et al. "Evidence of high-temperature exciton condensation in two-dimensional atomic double layers, Nature 574, 76 (2019).
[5] L. Sigl, et al. " Signatures of a degenerate many-body state of interlayer excitons in a van der Waals heterostack," Physical Review Research **2**, 042044(R) (2020).
[6] T. Deilmann et al. "Light–matter interaction in van der Waals hetero-structures", J. Phys.: Condens. Matter 32 333002 (2020).