Long-lived excitons in bilayer systems – exploring the phase diagram of composite bosons

Bastian Miller,1,2 Florian Sigger1,2, Jonas Kiemle1,2, Sebastian Dietl,1,2 Lukas Sigl,1,2 Alexander Holleitner,1,2 and Ursula Wurstbauer*1,2,3

1Walter Schottky Institut and Physics-Department, Technical University of Munich, Germany
2Nanosys Initiative Munich (NIM), Germany
3Lehrstuhl für Experimentalphysik, Universität Augsburg, Germany
*Corresponding author: wurstbauer@wsi.tum.de

Ensembles of indirect or interlayer excitons (IXs) are intriguing systems to explore classical and quantum phases of interacting bosonic ensembles. IXs are composite bosons that feature enlarged lifetimes due to the reduced overlap of the electron-hole wave functions resulting in dense IX ensembles thermalized to the lattice temperature. Besides IX ensemble in III-V heterostructures [1,2], transition metal dichalcogenides (TMD) exhibit excellent potential for studying interacting IX ensembles due to a strong light matter interaction together with a large exciton binding energy in these 2D materials [3]. Hetero-bilayers from these materials have a type II band alignment driving an efficient charge transfer between the two layers that results in the formation of spatially separated electron-hole pairs.

We focus on optical spectroscopy studies of IX ensembles hosted either in gate-tunable GaAs double quantum well (DQWs) structures or in van der Waals heterostructures prepared from TMDs. Lateral electrostatic confinement of the photogenerated electron-hole pairs in GaAs DQWs results in coexisting ensembles of excitons and 2D holes. Resonant inelastic light scattering experiments reveal a collective excitation mode at an energy of only 0.44 meV that is consistent with a plasma excitation of the 2D excess holes coherently coupled to the IXs [1].

Moreover, we observe of a doublet structure in the low-temperature photoluminescence of interlayer excitons in heterostructures consisting of monolayer MoSe2 and WSe2. Both peaks exhibit long photoluminescence lifetimes of several tens of nanoseconds up to 100 ns verifying the interlayer nature of the excitons [4]. The energy and line width of both peaks show unusual temperature and power dependences. We explain these findings by two kinds of interlayer excitons being either indirect or quasi-direct in reciprocal space [4]. Encapsulation in hexagonal boron nitride results in very narrow excitonic emission lines for the direct excitons [5], but also for the interlayer excitons [6]. Also for van der Waals hetero-bilayers, stark effect devices allows for the manipulation of the excitons by external electric fields. Our results provide fundamental insights into long-lived interlayer states in van der Waals heterostructures with possible bosonic many-body interactions.

We gratefully acknowledge financial support by the Deutsche Forschungsgemeinschaft (DFG) via excellence cluster “Nanosystems Initiative Munich” as well as DFG project WU 637/4-1.

References