**Nano-optical and paramagnetic investigations of optoelectronic heterostructures**

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This dissertation investigates light-matter interactions in heterostructure systems for applications in optoelectronics. Two main types of heterostructures are studied: van der Waals 2D heterostructures based on transition metal dichalcogenides (TMDs), and bulk heterojunctions (BHJs) in organic photovoltaics (OPVs). Nano-optical techniques and electron paramagnetic resonance (EPR) spectroscopy are employed for these studies.

Firstly, exciton-plasmon polaritons (EPPs) are explored in WSe2/Au heterostructures using scattering-type scanning near-field optical microscopy (s-SNOM). Strong exciton-plasmon coupling and significant Rabi splitting energy are revealed, with polariton properties linked to WSe2 thickness and field localization.

Further, we model gate-tunable cavity exciton-polaritons (EPs) in WS2 within Fabry–Pérot cavities. Finite element method (FEM) simulations highlight the sensitivity of EP dispersion and propagation length to gate voltages near exciton or trion energies, promising applications in nanophotonics and optoelectronics.

Additionally, we conduct a nano-infrared (IR) study of WTe2/SiO2 heterostructures using s-SNOM. Hybrid IR resonance shifts due to WTe2 on SiO2, attributed to WTe2's electronic effects altering SiO2 phonon dynamics.

Furthermore, the early kinetics of photo-generated defects in BHJ thin films are explored. EPR spectroscopy investigates photogenerated spin-active carbon dangling bond (CBD) defects in PCE12:PCBM and PCE12:ITIC blends. Defect creation mechanism follows a degradation-time-dependent power-law relationship, indicating monomolecular defect creation in BHJs. This insight aids in understanding light-induced defect formation mechanism in OPV materials.

These investigations enhance comprehension of light-matter interactions in diverse heterostructures, contributing to understanding novel phenomena, device design, and advancement of optoelectronic technologies.