Abstract

Two-dimensional (2D) semiconductors, particularly transition metal dichalcogenides (TMDs), and their heterostructures have gained attention for their unique electronic and optical properties, notably their ability to host excitons complexes. Precise control over exciton generation and transport in 2D heterostructures is essential for advancing optoelectronic devices. Traditional exciton engineering has focused on vertically assembled 2D p-n heterojunctions with electrical or strain-induced confinements, which limits scalability and performance. Lateral heterostructures (LHS) offer a promising alternative by providing spatially separated energy landscapes and strong in-plane bonding, controlling preferential exciton transport and interfacial phenomena. However, achieving atomically sharp interfaces and choosing specific 2D materials within LHS domains remains challenging. The primary goal of this thesis is to overcome some of these challenges.

The research investigates the synthesis, structural, optical and electronic characterization of 2D $MoSe_2$-WSe_2 LHS. Chemical vapor deposition (CVD) protocols were developed to synthesize group-VI TMDs $MoSe_2$-WSe_2 LHS, offering precise control over the number of in-plane junctions, layer thickness, domain size, and doping levels, all critical for the scalability and integration of these materials. The synthesized 2D LHS underwent comprehensive optical and electronic characterization, including reflection, Raman and photoluminescence (PL) spectroscopy, and transport measurements. At cryogenic temperatures (4K), the emission characteristics reveal pronounced exciton behavior, spectral shifts influenced by temperature, carrier densities, doping and dielectric environment, alongside valley coherence phenomena.

This study introduced novel field-effect transistor (FET) architectures utilizing monolayer and bilayer LHS. By integrating few-layer graphene and hBN into 2D LHS-based FETs, controlled generation and manipulation of excitons were achieved down to 4K. The work demonstrated fine-tuning exciton and trion characteristics through electrical manipulation, revealing how local electric fields and doping variations influence exciton dynamics and charge transfer. A novel n-p-n LHS FET architecture demonstrated multimode operation, including a reversible switch between positive and negative phototransistor characteristics. This switching, driven by trion generation, was achieved by carefully controlling external bias and tuning the excitation wavelength. The presence of trap states in WSe_2 expanded the operational range to near-infrared detection, making the device suitable for tunable exciton-based sensors and multifunctional devices. Another distinct device configuration reveals polarization-dependent tuning of the interfacial charge carrier transport characteristics via external bias, providing valuable insights into interfacial exciton dynamics.

Key milestones include fabricating multi-junction 2D LHS with precise structural control and tunable excitonic devices, paving the way for advancements in photonic devices, quantum communication, and future applications like excitonic transistors and quantum sensors.

Keywords: 2D Semiconductors, Lateral Heterostructure, Chemical Vapor Deposition, 2D Field Effect Transistor, Phototransistors, Exciton, Trion, Optoelectronic Device, Quantum Emitters, Polarization.