Abstract

Two-dimensional (2D) transition metal dichalcogenides (TMDs), with their unique properties, have drawn remarkable attention for fundamental research as well as for investigation on technological breakthroughs in various applications. The present dissertation demonstrates different pathways to realize hybrid transistors with superior performance for photodetection and synaptic applications utilizing various 2D TMDs and their nanostructures. High quality pristine monolayer WS_2 is mechanically exfoliated from bulk crystal on two different dielectric (SiO_2 and Al_2O_3) and a metallic (Au) substrate to study the behavior of quasiparticles (exciton, trion etc.) in the high carrier density regime with substrate variation. The anomalous behavior in photoluminescence spectral weight and resonance peak-shift are analyzed considering the influence of optical doping, substrate induced doping and dielectric screening. The red-shift-to-blue-shift crossover (RBC) of the excitonic peaks is observed for high carrier density regime (~ 10^{12} cm^{-2}) around the Mott transition point for the insulating (SiO_2/Si and Al_2O_3) substrates, which is absent for Au substrate, and is explained in light of many-body interactions in two-dimensional systems. Utilizing the few layer WS_2 as channel for its high carrier mobility and strongly light absorbing α-$CsPbI_3$ nanocrystals (NCs) as sensitizers, $CsPbI_3/WS_2$ mixed dimensional phototransistors have been fabricated for extended spectral response with enhanced responsivity. An asymmetric metal contact scheme has been facilitated to achieve ultralow dark current values (~ 10^{-12} A) without applying any gate bias. Owing to the successful charge transfer and strong photogating effect, the phototransistor exhibits a responsivity value of ~ 1.1×10^4 A W^{-1} and detectivity ~ 1.26×10^{13} Jones at a back gate voltage of ~ 40 V, demonstrating the superiority of the mixed dimensional phototransistor as compared to single channel based 2D phototransistors.

On the other hand, the size-dependent optical properties of semiconducting $CoTe_2$ have been reported by synthesizing different nanostructures (i.e., NSs, NCs, and QDs) using a simple, cost-effective yet efficient liquid-phase exfoliation technique followed by the gradient centrifugation method. The role of defect states due to the presence of Co-vacancies on the emission characteristics of quantum dot (QD) samples is analyzed via temperature dependent photoluminescence characteristics. Further, utilizing the two-color band photoabsorption of $CoTe_2$ NCs including UV-Visible and NIR regions, multi-wavelength recognizable optical synaptic devices based on $WS_2/ZnO/CoTe_2$ hybrid heterojunction are fabricated. The trapped holes in $CoTe_2$ NCs mediated longer recombination lifetime leads in short term as well as long term plasticity behavior in these devices, making them promising for artificial intelligence vision systems (AIVSs). Moreover, an effort has also been made to enhance the optical response of a van der Waals heterostructure (WS_2-ReS_2) through strong exciton-plasmon coupling using Au nanorods synthesized via chemical as well as electron beam lithography. The modulation of the transverse plasmonic peak of Au nanorods has been realized by varying the aspect ratio from 1:1 up to 1:10, leading to the tuning of coupling strength for high performance photodetector applications.

Keywords: *Transition metal dichalcogenides (TMDs), Excitonic complexes, Nanostructures, Hybrid heterojunction, Phototransistor, Optical synaptic device, Plasmonic*