Abstract of the Thesis

Emerging new physics from the layer-tunable optoelectronic properties of various two-dimensional (2D) materials captivated scientists for extensive research over the last decade. In the atomistic limit, 2D materials exhibit many interesting photo-physics that can even be modified by external means. In this dissertation, we explore the optical properties of solution-processed few-layer black phosphorus (BP) and molybdenum diselenide ($MoSe_2$) nanocrystals (NCs) and graphene quantum dots (GQDs) for applications in photodetection, demonstrating their superior performance. Size-dependent optical characteristics of few-layer $MoSe_2$ and BP NCs are studied and a progressive blue shift of near band edge absorption on reduction of the size is observed, which are useful for selective multicolour photodetection. Studies of thermodynamically stable, visible absorbing few-layer $MoSe_2$ NCs of varying size on Si show enhanced broadband (400–1400 nm) photoresponse in the heterojunction photodiodes ($MoSe_2$/Si), with the responsivity reaching up to 0.96 A/W. Furthermore, to enhance the photoresponse in visible to near-infrared region, 2D $MoSe_2$ nanoflakes are coupled with vertically standing ZnO nanorods ($MoSe_2$/ZnO NRs). The performance of this semitransparent broadband (300–900 nm) device could be improved with strategically integrating plasmonic Au nanoislands sandwiched between the semiconductors. On the other hand, BP is known to be relatively unstable and prone to attachment of various functional groups under ambient conditions. We demonstrate that without any external annealing BP NCs exhibit size-dependent thermal quenching of photoluminescence (PL) emission. BP NCs of relatively smaller size (~2.5 nm) exhibit a novel negative thermal quenching behavior as compared to positive one observed usually in bulk semiconductors and larger sized BP NCs. Moreover, optical absorption and emission characteristics of the BP nanoflakes could be controlled by plasmonic interaction. As confirmed by the spectroscopic analysis, plasmonic Ag-BP hybrids facilitate strong light-matter interactions beneficial for photodetection. Size-dependent optical properties of BP nanostructures and Ag-BP hybrids are utilized in Si compatible broadband (300–1600 nm) photodiodes (BP/Si and Ag-BP/Si) of high responsivity (~3.2 A/W). The utilization of highly luminescent 2D nanomaterials could also be beneficial to extend spectral response of commercially available visible photodetectors. GQDs with high PL quantum yield (57%) are applied to enhance ultraviolet response of a commercial Si photodiode by downshifting emission process and a relative enhancement of 200% is achieved. Various as-synthesized 2D materials based nanostructures are employed for mixed-dimensional photodetectors with extended and enhanced spectral response demonstrating their potential in nanophotonics.

Keywords: 2D materials, nanomaterials, molybdenum diselenide, black phosphorus, graphene quantum dots, plasmonics, multicolour photodetection