ABSTRACT

Limitation of use of graphene for optoelectronic devices due to its zero band gap and semi-metallic nature has explored the possibility of use of two dimensional transition metal dichalcogenides as an alternative material for these applications. Monolayer MoS_2 and $MoSe_2$ are two potential materials for future optoelectronic devices due to their layer number dependent band gaps. Devices with heterojunctions of 2D materials with covalent semiconductors are potential candidates for photodetector applications. GaAs being a direct band gap semiconductor with a band gap of 1.45 eV and mobility of 8000 $cm^2V\ s^{-1}$ is the most suitable bulk semiconductor for photodetector applications. Absorption of both GaAs as well as both the molybdenum dichalcogenides lies in the visible region of the solar spectrum. To enhance the operational wavelength of photodetectors based on 2D TMDs and GaAs the absorption cross-section of the 2D TMDs can be increased by formation of nanocomposites with materials which has absorption window beyond visible region, resulting in wider band photodetection.

In this dissertation, heterojunction devices of MoS_2 quantum dots with GaAs and $MoSe_2$-$Cu_{2-x}S$ nanocomposite on GaAs substrates have been demonstrated for photodetector applications. MoS_2 QDs with a dimension of ~2 nm, synthesized by standard sono-chemical exfoliation process of 2D layers have been used for the purpose. The photodetectors were fabricated using n-GaAs substrates with two different doping concentrations. The devices fabricated using GaAs having higher doping concentration exhibited a photo-to-dark current ratio order of $\sim10^2$, while the same with lower doping concentration showed an increase of the order of $\sim10^3$. The photodetector devices show a broadband operation over the visible wavelength range of 400 – 950 nm, with a peak responsivity of the devices being observed at 500 nm. The $MoSe_2$-$Cu_{2-x}S$ nanocomposites were synthesised using a colloidal route where defect sites present on solution processed $MoSe_2$ NSs act as nucleation centre for vertical growth of $Cu_{2-x}S$ islands, which results in the formation of nanocomposites with plasmonic characteristics. The devices with $MoSe_2$-$Cu_{2-x}S$/GaAs heterojunction exhibited a two colour-band spectral photoresponse in the wavelength region from 400 to 1600 nm, whereas the devices with $MoSe_2$/GaAs heterojunction exhibited a photoresponse in the wavelength region of 400 to 900 nm. This enhancement in

operating wavelength of the photodetector is due to absorption in NIR region by $Cu_{2-x}S$ nanoparticles.

Fabrication of devices based on semiconductor nanostructures require synthesis of these nanostructures in patterned array. Growth of these nanostructures in patterned array are typically carried out using nano-patterned substrates. The process for fabrication of sub 50 nm trenches as well as islands in PMMA has been demonstrated using electron beam lithography. The patterned array of trenches has been used further to pattern the Si_3N_4 film on Si. The patterned Si_3N_4/Si substrate was used to study the effect of patterning on growth of Ge using Molecular Beam Epitaxy. The pitch of the patterns has been varied to investigate its effect on the growth of Ge in comparison to un-patterned Si_3N_4. Theoretical simulation using Comsol Multiphysics has been carried out to analyse the observed growth pattern for different pitches of the patterned Si_3N_4.

Keywords: Two Dimensional Transition Metal Dichalcogenides, GaAs, Photodetector, Electron Beam Lithography, Ge nanostructures