Chapter 7 Conclusion and Future Scope of The Work

7.1 Conclusions

In conclusion, thesis work is mainly focused on the synthesis of thermal conducting and semiconducting two-dimensional (2D) MoS_2 nanostructures via chemical vapour deposition (CVD) technique and investigation of their photodetection and Surface-Enhanced Raman Scattering (SERS) applications. We have prepared three different morphologies of MoS_2 nanostructures- an interconnected network of few-layer MoS_2 over Si substrate, triangular bi-layer MoS_2 nanostructure over SiO_2/Si substrate and vertically oriented few-layer (VFL) MoS_2 nanostructure over Si substrate. The morphology of the prepared MoS_2 nanostructures have been studied using optical microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM) and atomic force microscopy (AFM) techniques. Further, to confirm the phase and the semiconducting nature of these materials, we have characterized these films via X-ray diffraction (XRD), Raman and Photoluminescence (PL) studies Thermal transport behaviour of triangular bi-layer MoS_2 over SiO_2/Si substrate and VFL-MoS_2 over Si substrate has been observed by optothermal Raman technique and corresponding thermal conductivities have been calculated. Thermal sensitive quantum confinement phenomenon has been observed in above samples by performing temperature dependent PL study, which provides the information about the tunable nature of their bandgap suitable for optoelectronics application. Based on the thermal conducting behaviour and semiconducting nature of prepared MoS_2 nanostructures, we have used these films for photodetection and SERS applications. The CVD grown MoS_2 nanostructures are n-type in nature and hence they form p-n heterojunction with p-type Si substrate. We have successfully demonstrated the photodetection application of interconnected network of few-layer MoS_2/Si heterojunction under white light illumination and VFL-MoS_2/Si heterojunction under green light illumination. In case of SERS application of prepared MoS_2 nanostructures, we have successfully detected organic pollutant (Rhodamine 6G - R6G) and Methyl orange (MO). We have successfully detected R6G molecule using all the prepared horizontal and vertical MoS_2 nanostructures, while MO molecule was detected using VFL-MoS_2 nanostructure.

Important Finding of The Present Work

- To the best of our knowledge, we have calculated thermal conductivity of vertically oriented few-layer (VFL) MoS_2 film for the first time using optothermal Raman (OTR) method. High thermal conductivity of ~100±14 W m^{-1} K^{-1} has been found for VFL-MoS_2 nanostructures, which is higher than other reports on pristine few-layer MoS_2 nanostructures. Higher thermal conductivity of VFL MoS_2 can be attributed to the minimal defects, suspended behaviour and reduced substrate effect in vertical orientation of MoS_2.
- We have also calculated the thermal conductivity and interfacial thermal conductance of SiO_2/Si supported horizontally grown triangular bi-layer MoS_2 nanostructure using OTR technique. Thermal conductivity of ~42 ± 8 W m^{-1} K^{-1} and interfacial thermal conductance of ~1.264 ± 0.128 MW m^{-2} K^{-1} for triangular bi-layer MoS_2 over SiO_2/Si substrate has been obtained.
- The prepared VFL-MoS_2/Si heterojunction shows excellent photoresponsivity of ~7.37 A W^{-1} under −2 V bias under low light illumination with intensity of 0.15 mW cm^{-2} of 532 nm laser. The good photo responsive behaviour of VFL-MoS_2 can be attributed to the strong light absorption due to multiple reflection of light in

interconnected network of vertical MoS_2, intralayer carrier transport speed and efficient electron-hole separation at VFL-MoS_2/Si interface.

- ❖ We have also successfully demonstrated SERS application of all three prepared MoS_2 nanostructures. The VFL-MoS_2 as a SERS substrate shows detection limit of 10^{-10} M concentration for Rhodamine 6G (R6G) and Methyl orange (MO). To the best of our knowledge, this is the highest detection limit among pristine MoS_2 nanostructures as SERS substrates. This high detection efficiency of VFL-MoS_2 can be attributed to improved light absorption due to enhanced light trapping by multiple reflections and higher accessible surface area for effective dye adsorption in vertical oriented network of MoS_2 nanosheets.
- ❖ The interconnected network of few-layer MoS_2 and triangular bi-layer MoS_2 nanostructures as SERS substrates show detection limit of 10^{-9} M for R6G molecule.
- ❖ Our study on differently synthesized MoS_2 nanostructures paves the way for technological advancement in optoelectronic devices and SERS based sensors.

7.2 Future Scope of the Work

- ❖ In future, CVD synthesis route can be explored to synthesize different 2D transition metal dichalcogenide (TMDs) materials and their Janus structures like MoSSe or heterostructures such as MoS_2/WS_2, $MoS_2/MoSe_2$ etc.
- ❖ Investigation of thermal transport behaviour and semiconducting nature of such Janus structures and heterostructures can be explored.
- ❖ These Janus structures or heterostructures can be explored for photodetection and SERS applications.
- ❖ In future, MoS_2 nanostructures and TMDs heterostructures can be transferred over flexible substrates for application in flexible optoelectronic devices.