Chapter-5

Conclusions and Future Scope

5.1 Major Conclusions

This thesis presents the performance investigation of some broadband photodetectors based on thermally grown $MoSe_2$ thin films. $MoSe_2$, a relatively less explored member of the transition metal dichalcogenides (TMDs) family, exhibits several promising properties, including high electrical conductivity, high in-plane carrier mobility, enhanced photoresponsivity, and fast transient response.

The literature survey in Chapter 1 reveals that the most commonly used methods for synthesizing TMDs are either simple mechanical exfoliation or more sophisticated chemical vapor deposition (CVD). While mechanical exfoliation is an easy method to isolate nanoflakes from bulk material, the resulting films often suffer from non-uniform flake distribution and uncontrolled thickness. Conversely, CVD allows for the controlled synthesis of uniform, high-quality mono- or few-layer TMD films, but at the expense of using highly complex and expensive deposition setups.

In this thesis, we explore a simple and cost-effective hydrothermal route for synthesizing $MoSe_2$ nanopowder, followed by its deposition on desired substrates using vacuum thermal evaporation. The main novelty of this work lies in the use of thermally grown $MoSe_2$ thin films for broadband photodetection applications. The key contributions of this thesis, presented in Chapters 2–4, are summarized in the **Table 5.1** given below:

In conclusion, the work presented in this thesis demonstrates that, similar to widely studied MoS_2 and WS_2 thin films synthesized by costly CVD techniques, $MoSe_2$ thin films grown via the inexpensive thermal evaporation method can also be effectively utilized for broadband photodetection applications.

Table 5.1 Summary Table comparing results covering all parameters of the three devices proposed in the thesis

Parameters	$MoSe_2$Thin film based MSM Broadband Photodetector	n-$MoSe_2$/ p-Si hetero-junction based Broadband Photodetector	ZnO CQDs/$MoSe_2$ hetero-junction based UV-Vis Broadband Photodetector
Substrate	SiO_2 /Si	p-Si	ITO
Bias Voltage	-1.5 V	-2 V	-2 V
Structure	Metal-Semiconductor-Metal junction	p-n heterojunction	n-n heterojunction
Dark current	~195 nA @ -1.5 V	~423 nA @ -2 V	~240 μA @ -2 V
Responsivity	~50 mA/W @415 nm	~316 mA/W @ 890 nm	~282 @ 370 nm; ~16.15 @ 550 nm
Specific Detectivity	1.54×10^{11} (Jones) @415 nm	~1.54×10^{11} (Jones) @ 890 nm	~9×10^{12} (Jones) @ 370 nm; ~5.37×10^{11} (Jones) @ 550 nm
EQE	~16 % @ 415 nm	~45 % @ 890 nm	~90000 % @ 370 nm; ~3660 % @ 550 nm
Rise time	17.76 msec	396 msec	7.25 s @ 370 nm; 1.2 s @ 550 nm
Fall time	18.38 msec	224 msec	(2.25 s) @ 370 nm; (2.2 s) @ 550 nm
Significance and Application	Its simple design, large active area, fast response and suitability for integration in optical systems make them suitable for diverse applications such as environmental monitoring, industrial imaging, medical applications etc.	They are widely employed to achieve high performance suitable for various high-tech fields such as industrial and civil applications, broadband detection, chip integrated circuits, optical commu-nication, etc.	Heterojunctions particularly using wide bandgap semiconductor like ZnO are crucial for UV detection applications such as UV astronomy, Bio-sensing, Defence application, Ozone monitoring, smoke detectors etc.

5.2 Future Work

$MoSe_2$-based photodetectors have demonstrated considerable potential in broadband photodetection due to their tunable bandgap, high carrier mobility, and strong light-matter interaction. Thus there are ample opportunities to explore this 2D material for many future studies:

- Though the present thesis considers the $MoSe_2$ thin film based broadband photodetector consisting of multilayer films, further exploration of monolayer or few-layer $MoSe_2$ can be explored for broadband photodetectors due to their enhanced quantum confinement effects to enable better control over optical absorption and electronic transport. E-beam evaporation or other advanced growth techniques or transfer methods can be optimized to obtain uniform, wafer-scale monolayers.
- Vertical and lateral heterostructures of thermally grown $MoSe_2$ thin films with other 2D materials (e.g., graphene, MoS_2, WS_2, h-BN) can be designed to achieve improved band alignment, enhanced photoresponsivity, faster carrier transport, and better suppression of dark current. $MoSe_2$/graphene or $MoSe_2$/black phosphorus heterojunctions, in particular, show promise for high-performance photodetectors across UV to NIR regions.
- With the increasing demand for wearable electronics and optoelectronic skins, attempts can be made to integrate the $MoSe_2$ onto flexible substrates (e.g., PET, PI) or transparent conductive oxides to develop bendable, lightweight, and transparent photodetectors for next-generation flexible electronics.
- Incorporating $MoSe_2$ into photovoltaic or piezoelectric-based energy-harvesting architectures can enable self-powered photodetectors that operate without

external bias. This can be especially beneficial for remote sensing, IoT devices, and implantable biomedical sensors.

- $MoSe_2$-based heterostructures can be engineered to mimic synaptic behavior for neuromorphic computing applications. Photodetectors with persistent photoconductivity or optical memory characteristics can be used in vision sensors and artificial intelligence hardware.
- Integrating $MoSe_2$ with plasmonic nanostructures (e.g., Ag, Au nanoparticles) or optical cavities can enhance local electromagnetic fields, thereby increasing light absorption and improving responsivity, particularly in specific spectral windows.
- For applications in optical communication and high-speed imaging, efforts should be made to minimize the response time of $MoSe_2$-based photodetectors through contact engineering, reduced trap densities, and improved interface quality.
- Controlled doping (e.g., with Nb, Re) or alloying (e.g., $MoS_{2x}Se_{2-x}$) can fine-tune the bandgap, carrier concentration, and electronic properties of $MoSe_2$, enabling custom-designed detectors for specific wavelengths or functionalities.
- The development of environmentally friendly, low-temperature, and scalable synthesis techniques (e.g., solution processing, inkjet printing) will be crucial for the commercialization of $MoSe_2$ photodetectors in consumer electronics and large-area imaging arrays.
- Thermally grown $MoSe_2$ thin film based photoconductive photodetectors can be studied. Interdigitated Ohmic contacts of Ti, Sc, Al or In metal can also be fabricated on the thermally grown $MoSe_2$ film on a SiO_2 coated Si substrate for such structures.