CHAPTER 5

Conclusion and Future Scope

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5.1 Major Observations

It is observed that perovskite materials have not been explored significantly for photodetection applications. Therefore, the primary objective of this thesis is to explore the inorganic perovskite $BiFeO_3$ and hybrid perovskite $CH_3NH_3PbI_3$ thin films for wideband photodetection applications. Three photodetector structures have been fabricated and characterized in present thesis: Indium doped tin oxide (ITO)/ZnO NPs/$BiFeO_3$ NPs/poly (3, 4-ethylenedioxythiophene): polystyrene sulfonate (PEDOT: PSS)/Ag; Fluorine doped tin oxide (FTO)/ZnO/$CH_3NH_3PbI_3$/MoOx/Ag and ITO/$BiFeO_3$/$CH_3NH_3PbI_3$/Ag. Major findings of the thesis are summarized in the following.

Chapter-2 reports the ITO/ZnO NPs/$BiFeO_3$ NPs/ PEDOT: PSS/Ag heterostructure based white light photodetector where n-type ZnO NPs and active layer $BiFeO_3$ NPs are synthesized using the sol-gel method and solid-state route, respectively. The formation of ZnO NPs/$BiFeO_3$ NPs heterojunction is confirmed by the measured capacitance-voltage *(C-V)* and current-voltage *(I-V)* characteristics. The proposed photodetector is shown to exhibit the photoresponse over a wide range of wavelengths 400-750 nm with a maximum responsivity of ~34 mA/W and EQE of ~8.8% over the specified visible range of 450-650 nm at an applied bias voltage of -2V. The device shows a rise time of 7.21 s and fall time of 6.23 s at -2 V bias voltage.

Chapter-3 presents the FTO/ZnO/$CH_3NH_3PbI_3$/MoOx/Ag heterostructure photodiode fabricated by the sol-gel method. The thin film characterizations show the hexagonal wurtzite crystalline structure of ZnO thin film and the tetragonal crystalline structure with high phase purity of the $CH_3NH_3PbI_3$. The photoresponse characteristics measured by applying a monochromatic light with varying wavelengths in the range of 350-700 nm show the maximum responsivity of ~21.8 A/W and EQE of ~6200% near the blue light (~436 nm) at a low bias voltage of -1 V.

Chapter-4 reports the ITO/$BiFeO_3$ NPs/$CH_3NH_3PbI_3$/Ag based photodetector where $BiFeO_3$ is used to serve as an optical filter-cum-ETL in the device. The $BiFeO_3$ NPs are synthesized by the solid route method and $CH_3NH_3PbI_3$ thin film has been grown by the sol-gel method as discussed in Chapter-2 and Chapter-3, respectively. $BiFeO_3$ NPs are shown to have a rhombohedral crystalline structure whereas the $CH_3NH_3PbI_3$ thin film has a tetragonal structure with high phase purity. Photoresponse characteristics of the proposed $BiFeO_3$ NPs/$CH_3NH_3PbI_3$ heterojunction photodiode are measured under incident monochromatic light with different wavelengths in the range of 400-900 nm. The photodetector shows the maximum responsivity of ~2 A/W, EQE of ~310%, and detectivity of ~$7.8x10^{12}$ $cmHz^{1/2}$/W at ~800 nm under -2 V bias voltage. The device also shows a rise time of 0.74 s and fall time of 0.088 s at -2V.

TABLE 5.1: Comparison $BiFeO_3$ based white light photodetector.

S.N.	Device Structure	Responsivity	Rise Time/ Fall Time	Reference
1.	ITO/ZnO NPs/$BiFeO_3$ NPs/ PEDOT: PSS/Ag	34 mA/W	7.21s/ 6.23s	This work
2.	ITO/PET/ZnO/$CH_3NH_3PbI_3$/ PEDOT: PSS/Au	40 mA/W	9s/ 6s	[27]

TABLE 5.2: Comparison of $CH_3NH_3PbI_3$ hybrid perovskite-based broadband photodetector.

S.N.	Device Structure	Responsivity (AW^{-1})	Reference
1.	FTO/ZnO/$CH_3NH_3PbI_3$/MoOx/Ag	21.8	This work
2.	FTO/ZnO/$CH_3NH_3PbI_3$/ spiro-OMeTAD/Au	7.8	[133]
3.	Si/SiO_2/ZnO/$CH_3NH_3PbI_3$/Ti/Au	4	[132]
4.	FTO/TiO_2/$CH_3NH_3PbI_3$/ spiro-OMeTAD/Au	0.85	[95]
5.	ITO/TiO_2/$CH_3NH_3PbI_3$/P3HT/MoO_3/Ag	0.25	[39]

TABLE 5.3: Comparison of perovskite-based ultraviolet to near-infrared region broadband photodetector.

S.N.	Device Structure	Responsivity	Detectivity (Jones)	EQE	Rise Time/ Fall Time	Reference
1.	ITO/$BiFeO_3$ NPs/$CH_3NH_3PbI_3$/Ag	2 A/W	$7.8 x 10^{12}$	310%	0.74s /0.088 s	This work
2.	ITO/ PEDOT: PSS $(FASnI_3)_{0.6}(MAPbI_3)_{0.4}$/$C_{60}$/BCP/Ag	0.2 A/W	$1.1 x 10^{12}$	65%	6.9μs/9.1μs	[57]
3.	ITO/PEDOT:PSS/$MA_{0.5}FA_{0.5}Pb_{0.5}Sn_{0.5}I_3$/ $PC_{61}BM$/bis-C_{60}/Ag	0.1 A/W	$1 x 10^{12}$	95%	_	[58]
4.	ITO/PTAA/$CH_3NH_3PbI_3$/ PDPPTDTPT:PCBM/BCP/Cu	_	$1 x 10^{11}$	40%	_	[91]
5.	ITO/PTTA/ $MAPbI_3$/F_8IC:PTB7-Th/ C_{60}/BCP/Cu	0.37 A/W	2.3×10^{11}	54%	5.6ns	[145]

TABLE 5.4: Comparison of our fabricated Photodetector.

S.N.	Device Structure	Responsivity	Detectivity (Jones)	EQE	Rise Time/ Fall Time
1.	ITO/ZnO NPs/$BiFeO_3$ NPs/ PEDOT: PSS/Ag	34 mA/W at (450-650 nm)	_	8.8%	7.21s/ 6.23s
2.	FTO/ZnO/$CH_3NH_3PbI_3$/MoOx/Ag	21.8 A/W at 436 nm	_	6200%	_
3.	ITO/$BiFeO_3$ NPs/$CH_3NH_3PbI_3$/Ag	2 A/W at 800 nm	$7.8 x 10^{12}$	310%	0.74s /0.088 s

The study of the inorganic perovskite $BiFeO_3$ and hybrid halide perovskite $CH_3NH_3PbI_3$ based photodetectors considered in the present thesis is expected to encourage the researchers to explore other perovskites for photodetection applications.

5.2 Future Scope of Work

Since research is an endless process, no research work is truly completed in all facets. There are always some limitations in the research works carried out in any thesis and the present thesis is not an exception to it. We would like to suggest some future scopes of research related to the thesis as listed below:

- Flexible hybrid halide perovskites-based photodetectors can be fabricated on polyamide, PET, PEN and clothes for wearable and smart photonics technology applications.
- Composites of inorganic/hybrid perovskite films can be investigated for optoelectronics applications.
- Hybrid perovskite heterojunctions with inorganic nanoparticles/quantum dots of other materials such as CNT and graphene can also be investigated for optoelectronic applications.
- Gas sensing properties of the perovskite materials considered in this thesis may also be investigated.
- Perovskite materials studied in this thesis can be used in photoelectrochemical water splitting reactions for hydrogen generation on account of their excellent optical and electronic properties.