Chapter 6

Conclusion and Future Scopes

6.1 Conclusion

In this thesis organic semiconductor and ZnO CQDs based heterojunction photodetectors are investigated for the performance improvement. The ZnO CQDs were synthesized using the hot injection method, which is suitable for large area and flexible electronics as well as low-cost solution processed fabrication. Organic, inorganic hybrid based heterostructures were utilized to enhance the extraction and efficient transportation of photogenerated carriers. We efficiently demonstrated the photomultiplication (PM) phenomenon to enhance responsivity. This PM phenomenon was enabled by ZnO CQDs. We also demonstrated the enhanced performance of Photodetectors using a thin interfacial layer of MoOx which acted as hole transport layer (HTL) and electron blocking layer (EBL). Moreover, the use of F8BT and MoOx interfacial layer resulted in the self-powered phenomenon with good time response and photocurrent gain. We successfully demonstrated small molecule and polymer blend (TIPS-Pentacene: F8BT) based blend, which helped in enhanced solution processed film quality in comparison to the small molecule. This thesis work is primarily focused on heterojunction photodetectors so the thesis is started with the introduction to the photodetectors and related literature. In this sub-section, the chapter wise summary of all the discussion and results is given as below:

Chapter 1 discussed some basics of photodetectors, performance parameters of photodetectors, some nanostructured materials for photodetectors, organic materials commonly used in photodetectors, state of the art review of organic photodetectors, heterostructures, photomultiplication phenomenon, review of organic photodetectors using photomultiplication phenomenon and brief review of recent self-powered UV photodetector.

Chapter 2 studied a p-type TIPS-Pentacene and n-type colloidal ZnO quantum dots (QDs) organic/inorganic heterojunction-based ultraviolet (UV) photodetector. The colloidal ZnO QDs of average sizes of ~1.77 nm are synthesized using a hot injection route. A thin film of ZnO colloidal quantum dots (CQDs) is first grown on an indium doped tin oxide (ITO) coated glass substrate using the spin coating method. The TIPS-Pentacene organic thin film is then grown on the ZnO CQDs layer by spin coating method. The photo response of the proposed structure is measured for monochromatic light of wavelengths in the range of 300-700 nm. The device exhibited maximum responsivity of ~59.15 A/W, external Quantum efficiency of ~ 19877%, detectivity of ~7.01×10^{13} cmHz$^{1/2}$/W at incident UV light with an intensity of 43 µW/cm^2 at an applied reverse bias of 1 V. The EQE value greater than 100% was attributed to the photomultiplication phenomenon arising due to intrinsic defects present in ZnO CQDs.

Chapter 3 investigated the effect of the MoOx interfacial layer on TIPS-Pentacene and ZnO CQDs based photodetector. The MoOx layer (~10 nm) acts as Hole transport layer and Electron blocking layer thereby suppressing the dark current. Furthermore, the MoOx layer minimizes recombination. Like the previous report, the synthesis of ZnO CQDs and deposition methods used were solution based. The device structure with ITO/ ZnO CQDs/ TIPS/ MoO_x/ Ag exhibits enhanced photo response. Upon illumination by a light of 386 nm and intensity of 46 µW/cm^2, the device achieves maximum responsivity (R) of approximately 217.24 A/W, a detectivity (D) of about ~ 6.79×10^{12} cmHz$^{1/2}$/W, an external quantum efficiency (EQE) of 69811.93 % .While on exposure to incident light of wavelength 640 nm and intensity of 48.8 µW/cm^2 at -1 V the device with MoOx interfacial layer demonstrates a responsivity (R) of around 57.34 A/W, a detectivity (D) of approximately 1.79×10^{12} cmHz$^{1/2}$/W, and an external quantum efficiency (EQE) of roughly 11111.3%.

Chapter 4 is devoted to the fabrication of F8BT and ZnO CQDs heterojunction-based photodetectors. The effect of the MoOx layer has been also studied in this chapter. Two devices with structure namely ITO/ ZnO CQDs/ F8BT/ Ag (Device-1) and ITO/ ZnO CQDs/ F8BT/ MoO_x/ Ag (Device-2) have been fabricated using the solution route and their comparative study has been presented in order to understand the role of MoOx layer. The device 2 with MoOx interfacial layer shows prominent self-powered phenomenon. The MoOx layer facilitates hole transport as well as electron blocking (by preventing electron injection from the anode under reverse bias). Device-2 (Device-1) achieved a maximum responsivity (R) of 44 A/W (24 A/W), a specific detectivity (D^*) of ~ 6.5×10^{12} Jones (1.3×10^{12} Jones) EQE of ~ 14171 % (7729%) rise-time (τ_{on}) and fall-time (τ_{off}) of 0.016 s (0.026 s), 0.018 s (0.030 s) respectively. All these parameters were obtained under a bias of -1 V and at light intensity of 25 μW/cm^2 (385 nm wavelength). Moreover, insertion of the MoOx interfacial layer in Device-2 resulted in prominent self-biased phenomenon with the maximum values of R, D^*, EQE, τ_{on} and τ_{off} as ~ 59 mA/W, 3.70×10^{10} Jones, 18.98 %, 0.012 s and 0.017 s, respectively under zero-bias operation and 25 μW/cm^2 intensity of 385 nm.

Chapter 5 presented a small molecule (TIPS Pentacene) and polymer (F8BT) p-type blend and ZnO CQDs (n type) based heterojunction-based photodetector. Two vertical structures namely ITO/ ZnO CQDs/ F8BT: TIPS-P/ Ag (Device 1) and ITO/ ZnO CQDs/ F8BT: TIPS-P/ MoO_x/ Ag (Device 2) has been fabricated. The polymer and small molecule blend combine the advantages of both, the high mobility of TIPS- Pentacene easy film and processability of polymer film. All the optical measurements and parameter extraction were carried out at incident monochromatic light source (intensity of 17.43 $\mu W/cm^2$) and in wavelength range of 350-700 nm. Use of MoOx layer resulted in enhancement of Responsivity from 29.60 A/W to 70.20 A/W, detectivity from 6.35×10^{12} Jones to 63.97×10^{13} Jones at 350 nm of the UV region. While in the visible region at 470 nm the insertion of MoOx layer resulted in enhancement of responsivity from 13.68 A/W to 40.92 A/W and detectivity from 2.93×10^{12} Jones to 2.08×10^{13} Jones.

6.2 Future Scope

Although the objectives of the work proposed in this thesis has been achieved still research is a dynamic process and cannot stop. So, there are many aspects that can be further studied or taken into account for further enhancing the performance. Some of the observations that might be taken into account in future regarding this works has been enlisted here. In the present thesis work, we have investigated the works on organic semiconductor and ZnO CQDs based heterojunction photodetectors. There are many other aspects of the device structure and synthesis of ZnO quantum dots that need to be further explored. The effect of the size of ZnO CQDs can be further studied to understand the photodetector performance. A study may also be carried out to understand the impact of the thickness of ZnO CQDs on photodetector performance. Moreover, investigation regarding the optimum thickness of the polymer layer or ratio of F8BT: TIPS pentacene needs to be studied. The existing structures could be used with ternary blends to make it a broadband photodetector. Furthermore, the blend of ZnO CQDs and TIPS Pentacene or F8BT could be explored for gas sensing performance owing to high surface to volume ratio of ZnO CQDs.