Chapter-5

Conclusions and Future Scope

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The main objective of this thesis was to investigate the potential applications of PTB7 polymer. In the previous chapters, the PBT7-based visible/white photodetectors and gas sensors are investigated. Now, the summary of different work on the PBT7-based devices is provided in this chapter. At the end of this chapter, the future scope of this thesis is also presented.

5.1 Major Conclusions

It was observed from Chapter 1 that PTB7 polymer was not explored for its potential broad-area applications. Only a few researchers have studied the photovoltaics and optical properties of the PTB7-based devices. This thesis makes a major contribution by exploring PTB7-based thin-film devices, optimizing their thin-film fabrication process, and researching their possible applications.

This thesis work aimed to discuss the unique properties of organic semiconducting materials, their advantages over inorganic semiconducting materials, and suitable low-cost thin film deposition methods adopted for organic semiconducting materials. The steps of substrate cleaning, sample preparation, and polymer coating were explained in detail. Metal-semiconductor-metal (MSM) and inverted device structures were studied for device fabrication followed by visible and white light sensing. Various characterizations for thin film and electrical properties were used for device sensing. The floating film transfer method (stamping method) with vertical device structure resulted in better device transient response compared to the spin coating method-based MSM structure device. FTM was found a new emerging method for organic polymer which offers better self-assembly of long polymer chains. The fabricated visible range photodetector can potentially be applicable in visible light communication and biomedical imaging.

The PTB7 thin film device was fabricated in MSM configuration for visible light detection. The polymer film was grown on Si/SiO_2 substrate through spin coating method at 2000 rpm. Al metal contacts were grown to make schottky junction using thermal evaporation method. The average surface roughness was measured as ~0.440 nm by dynamic contact mode AFM. The UV-Vis absorbance spectrum of the PTB7 film showed a peak absorbance ~665 nm and the band gap was estimated as 1.64 eV using tauc plot. The maximum current under dark conditions was recorded as ~140 nA and after light illumination, the photocurrent was recorded as ~1.9 μA at -3 V bias. The highest responsivity and EQE were calculated as 52.5 A/W and 9789% by illumination of 665 nm wavelength with light intensity of ~1.039 μW/cm^2). The photoconductive gain of MSM structure and surface defects in polymer film is the potential reason for high gain. The highest specific detectivity of this fabricated device was obtained as ~1.28×10^{13} Jones. The transient response of this device was recorded as 32 ms of rise time and 24 ms of fall time. This solution-processed PTB7 film device has potential application for visible light communication.

Another solution-processed PTB7 film was fabricated for white light sensing in this thesis work using FTM method. Si substrate with Al deposited at back was used for the vertical configuration of device. PTB7 film was obtained by FTM method, in which the polymer film is stamped on the substrate. For top contact electrode Al was deposited by thermal evaporation method. The white light was illuminated from the top of the device with varying intensity from 0.228 mW/cm^2 to 12.98 mW/cm^2 to study the optoelectronic properties of polymer film. The I-V measurements were performed from -2 to 2 V bias. The maximum responsivity and specific detectivity of ~146 mA/W and 4.137×10^{10} Jones were recorded respectively under the illumination of 0.228 mW/cm^2. The switching speed of the fabricated photodetector was achieved ~0.016 s as rise time and 0.112 s as fall time. This white light photodetector can be utilized for image sensing applications.

This thesis also includes the PTB7-based nanostructure devices for room temperature ammonia sensing. The fabricated device has shown a low-concentration detection of ammonia gas (2 ppm) and a high sensing response (50 ppm) with good selectivity. These sensors are also a modern necessity and have a wide utility in industrial and domestic applications for ammonia sensing.

The PTB7-based ammonia sensing device was studied at room temperature(~ 25 °C) in a gas chamber in dark conditions. ZnO nanorods were synthesized by well well-established hydrothermal route and characterized by XRD, FESEM and AFM techniques. The ZnO nanorods were measured as ~863 nm of average length and ~344 nm of average diameter. These as-fabricated ZnO nanorods were covered with PTB7 thin film using spin coating method for ammonia sensing. The average roughness of the PTB7 sensing layer was measured as ~175 nm by AFM characterization. The gas sensing properties of as-fabricated devices were examined under 2 V bias with varying gas exposure from 2 to 50 ppm concentration in the gas sensing chamber. The PTB7 decorated ZnO nanorods-based device has shown enhanced gas response as 66.92% while the pristine ZnO nanorod-based device has shown 15.56 % gas response at 20 ppm ammonia exposure at 2 volt bias. Both, the polymer thin film and nanostructure of ZnO layer collectively improved the gas sensing response by increasing the surface-to-volume ratio of the fabricated device. The minimum exposure of ~2 ppm ammonia was detected by fabricated device and measured gas sensing response as 7.12%. The maximum gas sensing response was recorded as 72.72% at 50 ppm ammonia concentration. The transient study of device computed the response time for 20 ppm ammonia exposure was 5 seconds while the recovery time was calculated as 30 seconds. The robustness of the fabricated device was analysed by varying relative humidity from 30% to 75%. The gas response was found as 73.23% in presence of 30% relative humidity, which decreased to 66.92% as relative humidity was increased to 75% at 20 ppm ammonia exposure. Selectivity test was also performed and found that the fabricated device has maximum response with ammonia gas compared to other exposed gas/vapors. The fabricated device showed high gas sensing response and good transient response for room temperature ammonia detection.

5.2 Future Work

The research work presented in this thesis inspires new opportunities as an extension of the work presented in this thesis. Nanotechnology is an emerging field for electronic device fabrication. Smart, flexible electronics are in great demand today, which is an inspiration for researchers. Two significant potential applications of the PTB7 polymer were investigated in this thesis work. However, PTB7 can be utilized for examining the other material-based properties for emerging technology applications. The following avenues are suggested for further research based on this work:

- Polymer PTB7 can be further investigated by doping with suitable material to improve the photodetection and gas sensing performance.
- PBT7-based devices can be investigated with different nanostructures for various sensing and biomedical applications.
- Flexible substrates-based devices can be fabricated for wearable electronics using PTB7 polymer.
- Organic thin film transistors (OFETs) can be fabricated for domestic and industrial applications.

- Further, these fabricated devices can be packaged as a complete setup after integrating with software for smart/intelligent sensors.