CONTENTS

Li	ist of Figur	es	xi-xiv
Li	ist of Tables	S	xv
Li	ist of Abbre	eviations	xvi-xvii
Li	st of Symbo	ols	xviii
P^{i}	reface		xix-xxi
C	hapter 1		1-28
	Introduc	ction and Scope of the Thesis	
1.1	Introduct	tion	1
1.2	Basics of	Organic Photodetectors	2
	1.2.1.	Definitions of Some Key Parameters of Organic Photodetectors	5
1.3	Literatur	e review of Some photodiode type broadband organic photodetectors.	7
	1.3.1	Thick Film Broadband Organic Photodetectors	8
	1.3.2	Ternary Nanocomposites Based Broadband Photodetectors	9
	1.3.3	Interface Engineering Broadband Photodetectors	
	1.3.4	Multilayered Broadband Photodetectors	11
1.4 Review of Some Photomultiplication (PM) effect Based Broadband Photodetectors			ctors14
	1.4.1	Photomultiplication via Traps in the Active Layer of Organic	
		Photodetectors	15
	1.4.2	Photocurrent Multiplication via Traps at Interfacial Layers Based	
		Photodetectors	19
	1.4.3	Electron/Hole Blocking Layer Based Photodetectors with Photocurr	rent
		Gain	21
1.5	Motivatio	n of the Thesis	25
1.6	Scope of t	the Thesis	26

ZnO Nanorods/PCDTBT: PCBM: PbS QDs Based High Performance
Inverted Structure Broadband Photodetectors

2.1 Introdu	uction	31
2.2 Experi	mental Methodology	33
2.2.1.	Materials Used and Synthesis	33
2.2.2.	Device Fabrication	35
2.3 Result	s and Discussion	35
2.3.1	Material and Electrical Characterization	36
2.3.2	Optical Characterization	39
2.4 Conclu	asions	47
Chapter 3		49-65
PCDTBT:	PCBM: CdSe Tetrapod Shaped Nanocrystals	s Hybrid
Nanocompo	osites based UV-Visible Photodetectors	
3.1 Introdu	uction	51
3.2 Experi	mental Methodology	52
3.2.1.	Materials Used and Synthesis	52
3.2.2.	Device Fabrication	53
3.3 Result	s and Discussion	54
3.3.1	Material Characterization	54
3.3.2	Electrical and Optical Characterization	57
3.4 Conclu	usions	64
Chapter 4		67-84
High Respo	onsivity ZnO Nanorods/ PTB7 Polymer Heter	rojunction Based
UV - Visibl	e Photodetector	
4.1 Introdu	uction	69

4.2 Experi	mental Methodology	70
4.2.1.	Materials Used and Synthesis	70
4.2.2.	Device Fabrication	72
4.3 Result	s and Discussion	72
4.3.1	Material Characterization	72
4.3.2	Electrical and Optical Characterization	76
4.4 Conclu	usions	84
Chapter 5		85-89
Conclusion	and Future Works	
5.1 Major Cor	ntributions	87
5.2 Scope of I	Future Work	89
References		91-101
List of Publice	ations	103-104

LIST OF FIGURES

Fig. 1.1:	Two terminal device architecture of the Organic Photodetectors	2
Fig. 1.2:	Organic photodetectors are mainly classified into three types: (a) Phototransistors-based OPDs (PT-OPDs).(b) Photoconductors-based OPDs (PC-OPDs). (c) Photodiodes-based OPDs (PD-OPDs)	4
Fig. 1.3:	Schematic view of energy band diagram of the device operating in photodiode mode.	7
Fig. 1.4:	The schematic device structure with MAPbI3 perovskite integrated with the binary organic blend of PTB7-Th: IEICO-4F (1:1.5, wt/wt)	12
Fig. 1.5:	Schematic view of energy band diagram of the device with PM effect realized through traps in the active layer	15
Fig. 1.6:	Broadband PM-OPDs device structure with traps (Q switch 1 molecules) in the active layer and Ir-125 NIR dye to extend the spectral range to NIR	17
Fig. 1.7:	Schematic layout of Broadband PM-OPDs device structure having traps in the interfacial layer.	19
Fig. 1.8:	Schematic view of energy band diagram of the device with PM effect realized through intrinsic traps in the interfacial layer	20
Fig. 1.9:	Schematic view of energy band diagram of the device with PM effect realized through charge blocking layer	22
Fig 2.1:	Represents the schematic of Hydrothermal synthesis of ZnO nanorods FTO glass substrate	33
Fig. 2.2	High-resolution SEM image of ZnO NRAs on FTO glass substrate (a) 1 μ m Scale (b) 3 μ m Scale. Top right inset in (b) is the corresponding enlargement.	35
Fig. 2.3:	Shows the absorbance plot of PCDTBT: PCBM: PbS QDs Ternary blends Nano Composite active layer. Inset shows the separate absorbance spectrum of ZnO NRAs, PbS QDs and PCDTBT: PCBM Composite.	35

Fig. 2.4:	Schematic representation of inverted broadband photodetector Device structure (Light illumination from glass Side)	36
Fig. 2.5:	Energy band diagram under Light Illumination at -1.5V bias.	37
Fig. 2.6:	Semi logarithmic J-V Plot of ZnO nanorods based Penetrated ETL device and ZnO thin film based non penetrated ETL device at dark and under illumination light of intensity 100 mW/cm ² .	38
Fig. 2.7:	Responsivity plot showing comparison of ZnO nanorods penetrated and ZnO thin film non penetrated ETL based device. Inset shows the significant enhancement in visible and NIR region.	39
Fig. 2.8:	Shows the EQE plot depicting the comparison of ZnO nanorods penetrated and ZnO thin film non penetrated ETL based device. Inset shows the significant enhancement in visible and NIR region.	40
Fig. 2.9:	Detectivity plot as a function of wavelength under -1.5 V bias showing device detectivity comparison with and without penetrated ETL.	40
Fig. 2.10:	Pictorial illustration of Interface Area (Light interaction Volume) with (a) planar and (b) penetrated device structure	41
Fig. 2.11:	Graphical illustration of improvement of the responsivity at three selected wavelengths by introducing penetrated ZnO NRAs ETL in PCDTBT: PCBM: PbS QDs composite System.	42
Fig. 2.12:	Mechanism of photocurrent generation, photocurrent losses and strategy to reduce such losses. (a) Generation of exciton by absorption of photon in the active layer. (b) After photon absorption charge transfer state is created at the interface. (c) separation of charge carrier as free charge carrier followed by charge transport through the bulk materials of the active layer. (d) Device with non-penetrated ETL results in somewhat more recombination of free charge carrier with in the active layer itself before reaching to electrodes. (e) Device with penetrated ETL reduces the probability of free charge carrier recombination.	43
Fig. 3.1:	Represents the schematic of Hydrothermal synthesis of ZnO nanorods.	52
Fig. 3.2:	(a). Schematic of inverted device structure (b) Flat energy band diagram of the proposed device	53
Fig. 3.3:	Typical TEM micrograph of CdSe NCs (a) 100 nm and (b) 50 nm scale	53
Fig. 3.4:	HRSEM image of as-grown ZnO nanorods on FTO substrate (a)1 -	54

	μm scale (b) 100 nm scale.	
Fig. 3.5:	UV-Visible absorption plot of tetrapod shaped CdSe nano-crystals, PCDTBT: PCBM and PCDTBT: PCBM: CdSe Tetra pod nano-composites respectively	55
Fig. 3.6:	Logarithmic Current Density -Voltage (J-V) plot under dark and illumination condition of a broadband light source of intensity 100 mW/cm2.	56
Fig. 3.7:	Photoresponse plot of the device under light modulation (on/off) (a) multiple cycles of photoresponse under broadband light intensity with power density (Pd) of 100 mWcm-2 (b) UV-375 nm with Pd of 13.1μ Wcm-2 and (c) Visible-540 nm light with Pd of 41.2μ Wcm ⁻² respectively	57
Fig. 3.8:	Response time calculation of the device illuminated with (a) wavelength 375 nm (UV) under Pd of 13.1 μ Wcm ⁻² (b) wavelength 540 nm (Vis) under Pd of 41.2 μ Wcm ⁻²	58
Fig. 3.9:	Pictorial illustration of the mechanism in the proposed device under excitation of visible light.	59
Fig. 3.10:	Responsivity (R λ) and Detectivity (D) plot as a function of over a spectral range from 350 to 700 nm.	60
Fig. 3.11:	EQE plot as a function of over a spectral range from 350 to 700 nm	61
Fig. 4.1:	Schematic of ZnO nanorods synthesis by using low cost hydrothermal.	67
Fig. 4.2:	ZnO nanorods high resolution SEM (HRSEM) image as grown on FTO substrate at 400 nm scale with magnified version at 100 nm scale shown at the inset.	69
Fig. 4.3:	(a) Cross sectional FE-SEM image of ZnO NRs/PTB7 bilayer layer;(b) Cross-sectional image of the ZnO NRs layer only.	69
Fig. 4.4:	The absorption profile of the ZnO NRs layer and ZnO NRs/PTB7 bilayer. Inset sows the separate absorption plot of the PTB7 polymer.	70
Fig. 4.5:	(a) The schematic diagram of the fabricated device (b) Depicts the energy level alignment of our proposed device	71
Fig. 4.6:	Represents energy band diagram with corresponding photo charge carriers transport mechanism at reverse bias and forward bias condition respectively	72

Fig. 4.7:	Current density -Voltage (J-V) spectra under dark and UV -380 nm illumination of the proposed device in Linear scale. Inset of Fig.4.7 depicts the Capacitance (C)-Voltage (V) plot at 1 MHz frequency	73
Fig. 4.8:	Current density -Voltage (J-V) spectra under dark and UV -380 nm illumination of the proposed device in logarithmic scale.	74
Fig. 4.9:	Repeatability analysis under similar operating condition dark current - voltage curve of 4 devices.	75
Fig. 4.10:	Responsivity plot over spectral range from 300 nm - 900 nm wavelength.	76
Fig. 4.11:	EQE and Detectivity Plot as a function of wavelength over broad spectral range from rom 300 nm - 900 nm wavelength.	78
Fig. 4.12:	(a) Current (I)—Time (t) plot under on/off modulated light of 380 nm with $\sim\!20.07~\mu\text{Wcm-2}$ intensity (b) Response speed calculations of the device.	79

LIST OF TABLES

Table 1.1:	Comparison of some key parameters of broad band organic	11-12
	photodetectors based on photodiode type with different active	
	layers and strategies.	
Table 1.2:	Comparison of some key parameters of broad band organic	20-22
	photodetectors based on photocurrent multiplication	
	phenomenon with different active layers and strategies.	
Table 2.1:	Comparison of some Organic Materials based Photodetectors	41-42
Table 4.1:	Comparison of the responsivity with different ZnO NRs/polymer heterojunction-based photodetectors in the literature.	71-72