CERTIFICATE

It is certified that the work contained in the thesis titled **"Fabrication and Characterization of PCDTBT:PC_{61}BM Based Bulk Heterojunction Organic Solar Cell"** by **"Amit Kumar"** has been carried out under our supervision and this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive, Candidacy and SOTA for the award of Ph.D. Degree.

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I, Amit Kumar, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of Prof. Satyabrata Jit and Dr. Bratindranath Mukherjee from "21/07/2015" to “12/04/2021”, at the Department of Electronics Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, *etc*., reported in journals, books, magazines, reports, dissertations, theses, *etc*., or available at websites and have not included them in this thesis and have not cited as my own work.

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Date: **(Amit Kumar)**

Dedicated
To
My Family

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Details
OPV	Organic photovoltaic
OSC	Organic solar cell
BHJ	Bulk heterojunction
EPBT	Energy payback time
EQE	External quantum efficiency
MEH-PPV	Poly[2-methoxy-5-(2’-ethylhexyloxy)-1,4-phenylene vinylene]
PCDTBT	poly[N-9′-hep- tadecanyl-2,7-carbazole-alt-5,5-(4′,7′-di-2-thienyl-2′,1′,3′-ben- zothiadiazole)]
PCBM	[6,6]-phenyl-C_{61}-butyric acid methyl ester
ETL	Electron transport layer
HTL	Hole transport layer
P3HT	Poly(3-hexylthiophene)
PQT-12	Poly(3, 3′′′-dialkylquaterthiophene) or
	Poly(3,3′′′-didodecylquaterthiophene)
FTM	Floating-film transfer method
IL	Interface layer
HOMO	Highest occupied molecular orbital
LUMO	Lowest unoccupied molecular orbital
AM	Air mass
PBTTT	Poly[2,5-bis(3-tetradecylthiophen-2-yl)thieno[3,2-b]thiophene]
PEDOT	Poly(3,4-ethylenedioxythiophene)
PSS	Polystyrene sulfonate
eV	Electron volt
V_2O_5	Vanadium oxide
PPV	Poly(p-phenylene vinylene)

TiO_2	Titanium dioxide
PCE	Power conversion efficiency
MDMO-PPV	([2-methoxy-5-(3',7'-dimethyloctyloxy)]-1,4-phenylenevinylene)
HRSEM	High resolution scanning electron microscopy
UV-Vis	Ultraviolet-visible
PL	Photoluminescence
ZnO	Zinc oxide
PET	Polyethylene terephthalate
CdSe	Cadmium selenide
QDs	Quantum Dots
SnO_2	Tin oxide
Au	Gold
Ag	Silver
Al	Aluminum
MoO_3	Molybdenum trioxide
ITO	Indium-doped tin oxide
FTO	Fluorine-doped tin oxide
Si	Silicon
In_2O_3	Indium oxide
MEA	Monoethanolamine
PVDF	Polyvinylidene fluoride
DI	Deionized
IPA	Isopropanol alcohol

LIST OF SYMBOLS

Symbol	Details
λ	Wavelength
η	Power conversion efficiency
n	Ideality factor
R	Responsivity
α	Absorbance coefficient
IV	Current-voltage
JV	Current density-voltage
Eg	Energy band gap
IP_D	Ionization potential of the donor
EA_A	Electron affinity of the acceptor
E_B	Binding energy of the excitons
μ	Mobility
E_{HOMO}	Energy level of HOMO
E_{LUMO}	Energy level of LUMO
e	Charge of electron
I_{dark}	Dark current
I_d	Diode current
I_{so}	Reverse saturation current
I_{ph}	Photo generated current
Jo	Reverse saturation current density
V_T	Thermal equivalent voltage
Rs	Series resistance
Rsh	Shunt resistance

Isc	Short circuit current
Jsc	Short circuit current density
Voc	Open circuit voltage
FF	Fill factor
Vm	Maximum voltage
Im	Maximum current
Pmax	Maximum output power
Pin	Input incident power

PREFACE

Bulk heterojunction (BHJ) based organic solar cells (OSCs) are gaining greater attention for clean energy production due to various features, namely low-cost, easy fabrication process, the feasibility of solution process, mechanical flexibility, non-toxicity, and biodegradability. Recently, the low bandgap polymer, poly[N-9′-heptadecanyl-2,7-carbazole-alt-5,5-(4′,7′-di-2-thienyl-2′,1′,3′-benzothiadiazole)] (PCDTBT) has been considered to be more suitable p-type donor polymer for the OSC. The PCDTBT is blended with the commonly used acceptor polymer $PC_{61}BM$ for the fabrication of OSC and provides better stability as well as improved photovoltaic parameters. Considering the above aspects, the present thesis is focused to fabricate and characterize the PCDTBT:$PC_{61}BM$ active layer based BHJ OSC by modifying the interface layer, transport layers, and the photoactive layer. The works of the thesis are intended to enhance the photovoltaic parameters through thin film engineering. The thesis consists of five chapters which are briefly outlined in the following sentences.

Chapter-1 introduces the inorganic and organic semiconductors and charge conduction mechanism through them. A brief discussion on solar cells is included. Further, various types of organic solar cells, including the BHJ OSC, are discussed along with working principles and important photovoltaic parameters. A detailed literature survey followed by the scope of the present thesis has been finally outlined in this chapter.

Chapter-2 reports the PQT-12 polymer-based interface layer (IL) effect for the improvement in the photovoltaic parameters of the BHJ OSC. The floating film transfer method (FTM) is adopted for the deposition of PQT-12 thin film. Two distinct BHJ

OSCs have been fabricated in the device structure of ITO/ZnO QDs/PCDTBT:PC_{61}BM/PEDOT:PSS/Ag and ITO/ZnO QDs/PCDTBT:PC_{61}BM/PQT-12/PEDOT:PSS/Ag for the comparative study. The effect of PQT-12 IL has been investigated by several characterizations, namely current-voltage characteristics, absorbance, photoluminescence (PL), impedance spectroscopy, and external quantum efficiency. The OSC with the PQT-12 based IL has shown improved photovoltaic parameters.

Chapter-3 investigates the effect of thickness variations of the electron transport layer (ETL) as well as hole transport layer (HTL) on the performance of PCDTBT:PC_{61}BM based BHJ OSCs. The BHJ OSCs are fabricated in ITO/ZnO QDs/PCDTBT:PC_{61}BM/PQT-12/Ag structure, where ZnO QDs and PQT-12 are used as ETL and HTL, respectively. ZnO QDs ETL has been deposited by a solution-processed spin coating method, whereas PQT-12 HTL has been deposited using the FTM technique. The best OSC device performance has been obtained with the 35 nm ZnO QDs and 20 nm PQT-12 thicknesses.

Chapter-4 deals with the fabrication and characterization of two distinct BHJ OSCs in the device structures, ITO/ZnO QDs/PCDTBT:PC_{61}BM/MoO_3/Ag and ITO/ZnO QDs/PCDTBT:PC_{61}BM:CdSe QDs/MoO_3/Ag. The synergistic effect of CdSe QDs and PC_{61}BM is investigated in the ternary OSC device, where ZnO QDs and MoO_3 are used as ETL and HTL, respectively. The device structure, ITO/ZnO QDs/PCDTBT:PC_{61}BM:CdSe QDs/MoO_3/Ag has shown the improved photovoltaic parameters compared to other OSCs described in Chapter-2 and Chapter-3. The maximum efficiency of 5.02% is achieved due to the synergistic effect of CdSe QDs and PC_{61}BM.

Chapter-5 includes the major findings of the thesis along with a brief outline for the future scope of research related to the present thesis.

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CHAPTER 1

Introduction and Scope of the Thesis

Contents