



Daffodil International University
Dhaka, Bangladesh

Familiarization with Organic Photo-voltaic Cell and Simulation of Single layer and Multi-layer active cell for improving efficiency and fill factor

This thesis has been submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering.

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A Thesis Presented to the Academic Faculty

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APPROVAL

This Thesis title **“Familiarization with Organic Photo-voltaic Cell and Simulation of Single layer and Multi-layer active cell for improving efficiency and fill factor”** submitted by **Juwel Mia** to the Department of Electrical and Electronic Engineering, Daffodil International University, has been found as satisfactory and accepted for the partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering.

Board of Examiners:

DECLARATION

I hereby declare that this thesis is based on the result found by my selves. The materials of work found by other researchers are mentioned by reference. This thesis is submitted to Daffodil International University for partial fulfillment of the requirement of the degree of B.Sc. in Electrical and Electronics Engineering. This thesis neither in whole nor in part has been previously submitted for any degree.

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CONTENTS

	Page no.
DECLARATION	i v
LIST OF FIGURES	x i
LIST OF TABLES	x i i
ACKNOWLEDGEMENTS	x i v
ABSTRACT	xv
CHAPTER- 1: HISTORY OF ORGANIC SOLAR CELL	1
1.1 Inuctrodction.	1
1.2 A Short History Of organic solar Cell	2
1.3 Types of Organic Solar Cell	2
1.3.1 Small-molecule OPV cells.	2
1.3.2 Polymer-based OPV cells.	2
1.4 Thesis Objective.....	3
CHAPTER-2: PHOTOVOLTAIC CELL.....	5
2.1 Photovoltaic (PV) Cell Fundamental Principle.....	5.
2.2 Solar Radiation and Ideal Conversion Efficiency	8
2.3 Theory of I-V Characterization	10
2.3.1 Short Circuit Current ISC.	10
2.3.2 Open Circuit Voltage VOC.	11
2.3.3 Maximum Power (P _{MAX}), Current at P _{MAX} (I _{MP}), Voltage at P _{MAX} (V _{MP})	11
2.3.4 Fill Factor	12
2.4 Efficiency	15
2.4.1 Temperature Measurement Considerations	15

2.4.2	I-V Curves for Modules	16
CHAPTER-3:	ORGANICPHOTOVOLTAIC CELL	17
3.1	Background and Basic Concept	17
3.2	General Operation and Construction	21
3.2.1	Requirement of Band Gap and HOMO-LUMO Energy Levels	22
3.3	Molecule Design	23
3.3.1	Donor Molecules	25
3.3.2	Acceptor Molecules	26
3.4	Basic OPV Cell Structure	27
3.4.1	Single Layer Cell	27
3.4.2	Double Layer Cell	27
3.4.3	Blend Cell	29
3.5	Current Challenges and Recent Progress	29
3.5.1	Charge Carrier mobility & Transport	30
3.6	Typical Polymer Used in OPV Cells	30
3.6.1	Single Layer OPV cell active layer materials	30
3.6.2	Bulk hetero-junction OPV cell polymers	31
3.7	Brief Description about few Polymers	31
3.7.1	Fluorene based copolymers	31
3.7.2	Carbazole-Based Copolymers	31
3.7.3	Cyclopentadithiophene-Based Copolymers	32
3.7.4	P3HT:PCBM	33
3.7.5	P3HT:PCBM under Thermal Annealing	34

3.8	Effect of interface in organic photovoltaic	34
3.8.1	Origin of VOC.....	35
3.8.2	Determination of Polarity-Inverted and Non-Inverted Structure	35
3.9	Optical Spacer	35
3.9.1	ZnO as Optical Spacer	36
3.9.2	Solution-based Titanium oxide as Optical Spacer	37
3.10	Interface Materials for OPV cell	37
3.10.1	p-doped Polymers	37
3.10.2	Roles of Metal-oxide materials	39
3.11	Electrode requirements for organic solar cells	40
3.12	Materials for Transparent Electrodes	40
3.12.1	Indium Tin Oxide (ITO)	40
3.12.2	Other Type of Materials	41
CHAPTER-4:COMPARATIVE STUDY		42
4.1	Differences in structure and working principle of OPV and IPV ...	43
4.2	Reasons to choose OPV over IPV	44
4.3	Shortcomings of Organic Photovoltaic Cell	44
4.4	Remarks on OPV cells' future	44
CHAPTER-5: SIMULATIONS RESULTSANDCONVERSATION		45
5.1	Simulation Output from Single Layer OSC	45
5.1.1	C-60 based Fullerene as Active Layer	45
5.1.2	PEDOT: PSS as Active Layer	46

5.1.3	CuPC as Active Layer	46
5.1.4	P3HT (poly(3-hexylthiophene-2,5-diyl) as Active Layer	48
5.2	Simulation Output for Bulk hetero-junction OSC	49
5.2.1	P3HT.PCBM as active Layer	51
5.2.2	PTD7.PC71BM as Active Layer	51
5.2.3	PCDTBT.PC60BM as Active Layer	52
5.3	Simulation Output after changing contact sizes	52
5.3.1	PCDTBT: PC70BM as Active Layer	52
5.3.2	PBDTTT: PDI as Active Layer	53
5.3.3	PBDTTT: PDI60 as Active Layer	55
5.4	Discussions	56
5.4.1	Single Layer Organic Solar Cell	57
5.4.2	Bulk-heterojunction Organic Solar Cell	60
CHAPTER-6:CONCLUSIONS		61
REFERENCES		65

List of Figures

Figure 2.1	Solar spectrum at different air-mass conditions	6
Figure 2.2	Solar spectrum in photon flux density per photon energy	6
Figure 2.3	Idealized equivalent circuit of solar cell under illumination	7
Figure 2.4	Total number of photons in the solar spectrum (of AM1.5) above an energy value	8
Figure 2.5	I-V Curve of PV Cell and Associated Electrical Diagram	9
Figure 2.6	Simplified Equivalent Circuit Model for a Photovoltaic Cell (Including Non-idealities)	10
Figure 2.7	Illuminated I-V Sweep Curve	10
Figure 2.8	Maximum Power for an I-V Sweep	11
Figure 2.9	Getting the Fill Factor From the I-V Sweep	12
Figure 2.10	Effect of Diverging R_S & R_{SH} From Ideality	14
Figure 2.11	Obtaining Resistances from the I-V Curve	14
Figure 2.12	I-V Curve of Solar Cell Without Light Excitation	15
Figure 2.13	Temperature Effect on I-V Curve	15
Figure 2.14	I-V Curve for Modules and Arrays	16
Figure 3.1	Generic OPV consisting of a donor and acceptor sandwiched between	

	two electrodes	18
Figure 3.2	Small cell under illumination showing exciton formation, migration & dissociation	18
Figure 3.3	Conversion steps and loss mechanism of optical power to electrical power	19
Figure 3.4	Structures of high mobility benzene ring	20
Figure 3.5	Schematic of charge photogeneration & transport in excitonic PV	21
Figure 3.6	Energy diagram of donor and acceptor HOMO-LUMO levels showing three intercorrelated parameters: E_g , E_d & V_b	23
Figure 3.7	Various bonding and anti-bonding levels	24
Figure 3.8	Few examples of commonly used donor polymer	25
Figure 3.9	Few examples of commonly used acceptor polymers	26
Figure 3.10	Structure of single layer OPV	26
Figure 3.11	Typical Bilayer PV cell structure	27
Figure 3.12	OSC made from Bulk-heterojunction	28
Figure 3.13	Structures of P3HT and PCBM	33
Figure 3.14	Absorption spectrum of P3HT:PCBM	33
Figure 3.15	Intensity Curve & Effect of Thermal Annealing	34
Figure 3.16	ZnO as Optical Spacer & I-V Characteristics	36
Figure 3.17	The chemical structure of TiO_x	37
Figure 3.18	Spatial distribution of the squared optical electrical field strength	37
Figure 3.19	Structures of multilayer transparent electrodes based on organic materials	41
Figure 5.1	Schematic diagram of an OPV with P3HT	47

Figure 5.2	I-V characteristics curve of P3HT single layer cell	47
Figure 5.3	Photon Absorption Density of P3HT single layer cell	48
Figure 5.4	Photon Absorption at different stage of P3HT single layer cell	48
Figure 5.5	Schematic diagram of an OPV with P3HT.PCBM as active layer	50
Figure 5.6	I-V characteristics curve of P3HT.PCBM blend organic cell	50
Figure 5.7	Photon Absorption Density of P3HT.PCBM blend organic cell	51
Figure 5.8	Photon Absorption Distribution of P3HT.PCBM blend organic cell	51
Figure 5.9	Schematic diagram of an OPV	54
Figure 5.10	I-V characteristics curve of PBDTTT: PDI60 blend organic cell	54
Figure 5.11	Photon Absorption Density of PBDTTT: PDI60 blend organic cell	55
Figure 5.12	Photon Absorption Distribution of PBDTTT: PDI60 blend organic cell	55
Figure 5.13	Efficiency & Fill Factor Comparison for Single Layer Organic Solar Cell Models	57
Figure 5.14	Efficiency & Fill Factor Comparison for bulk-heterojunction blend Organic Solar Cell Models for 150nm thickness	58
Figure 5.15	Efficiency & Fill Factor Comparison for bulk-heterojunction blend Organic Solar Cell Models for 100nm thickness	60

List of Tables

Table 4.1 Comparison between organic and inorganic PV cells	42
Table: 5.1 Data for C-60 based Fullerene as Active Layer	45
Table: 5.2 Data for PEDOT:PSS as Active Layer	46
Table: 5.3 Data for P3HT as Active Layer	46
Table: 5.4 Data for P3HT.PCBM as Active Layer	49
Table: 5.5 Data for PCDTBT: PC70BM as Active Layer	52
Table: 5.6 Data for PBDTTT: PDI as Active Layer	53
Table: 5.7 Data for PBDTTT: PDI60 as Active Layer	48

Abbreviation of some short terms

PV	: Photovoltaic
OSC	: Organic Solar Cell
Voc	: Open Circuit Voltage
ISC	: Short Circuit Voltage
FF	: Fill Factor
HOMO	: Highest Occupied Molecular Orbital
LUMO	: Lowest Unoccupied Molecular Orbital
ITO	: Indium Tin Oxide

ACKNOWLEDGEMENTS

I express my sincere gratitude and indebtedness to the thesis supervisor **Dr. Md. Alam Hossain Mondal**, Department of Electrical and Electronic Engineering, Daffodil International University (DIU), Dhaka, Bangladesh for his cordial encouragement, guidance and valuable suggestions at all stages of this thesis work.

I express thankfulness to **Prof. Dr. M. Shamsul Alam**, Honorable Dean of the Faculty of Engineering, and Daffodil International University (DIU) for providing us with best facilities in the Department and his timely suggestions.

I used the "GPVDM" software developed by Dr. Roderick MacKenzie, an assistant professor in the faculty of engineering of The University of Nottingham for all our simulation purpose. I would like to thank him in this regard.

Last but not least I would like to thank all of my friends and well-wishers who were involved directly or indirectly in successful completion of the present work.

ABSTRACT

Organic photovoltaic has been developed for more than 30 years, however, within the last decade the research field gained considerable in momentum. The amount of solar energy lighting up Earth's land mass every year is nearly 3,000 times the total amount of annual human energy use. But to compete with energy from fossil fuels, photovoltaic devices must convert sunlight to electricity with a certain measure of efficiency. For polymer-based organic photovoltaic cells, which are far less expensive to manufacture than silicon-based solar cells, scientists have long believed that the key to high efficiencies rests in the purity of the polymer/organic cell's two domains -- acceptor and donor.

The basic principle of organic solar cells is to place layer(s) of organic electronic material between two metallic conductors of two different work functions. This difference of work function sets up an electric field within the organic layer(s) which when absorbs light, causes the excited electrons to be pushed towards positive electrode and holes towards negative electrode. This thesis has been based on an optimized two-layer organic solar cell which aims to increase the photon absorption by increasing the interface area between donor and acceptor levels.

This report summarizes the latest advances in the interfacial layers for bi-layer OSCs (including bulk hetero-junction photovoltaic cells). Finally, a brief summary and some perspectives about the current challenges and opportunities have been presented about this interesting area of research.

Dedicated to

**MY PARENTS
TEACHERS**

With Love & Respect

Chapter 1

History of Organic Solar Cell

1.1 Introduction

The worldwide vitality asset situation is experiencing a critical change as we are coming up short on petroleum derivative based vitality sources step by step. Sustainable power sources stood out enough to be noticed as an option in contrast to petroleum derivatives primarily because of its ease and eco-accommodating highlights. Reaping vitality legitimately from daylight utilizing photovoltaic innovation has developed as a standout amongst the most encouraging innovation to address regularly developing overall vitality request. The innovation utilized for assembling photovoltaic cells is prevalently founded on silicon which is an inorganic material. Early research works showed that joining regular semiconducting polymers had positive effect on the efficiency rate of the daylight based cells. In spite of the way that the efficiency rate of Organic Photovoltaic Cell is still low appeared differently in relation to inorganic photovoltaic cells, natural cells are promising because of their affinity for synthetic change (by means of concoction blend methods), their low assembling expense and the potential for substantial scale creation. These three reasons have prompted the push for looks into on natural sun oriented cells.

Natural Solar Cell (OSC) permits extensive territory manufacture of natural semiconducting polymers on lightweight and adaptable substrates utilizing ease arrangement preparing techniques. OSCs are typically included p-doped (electron contributor) and n-doped (electron acceptor) materials that are joined to shape a functioning layer, called the Bulk Heterojunction (BHJ). The slimness of the cell is the characterizing normal for this natural sun based cell innovation. Dissimilar to silicon-wafer cells, which have light retaining layers that are customarily 350 microns thick, the slim film OSCs have light engrossing layers that are only one micron thick[1]. The gap remains on the polymer while the excitons are separated, along these lines the charge transporters are presently spatially isolated. Despite the fact that living on two separate materials, electrons and gaps are as yet bound by coulomb power, however the recombination rate is unmistakably brought down (lifetime in miniaturized scale to millisecond run contrasted with that of nanosecond run in single excitons[2]).

1.2 A Short History of Organic Solar Cell

The infancy of organic solar cells began in the late 1950s [3]. At this time, photoconductivity in some organic semiconductor cells were measured with voltage of 1 V by some research groups. They proposed that if a single layer PV cell is illuminated consisting of an organic layer, sandwich cell with low work function metal (aluminum, Al) and a conducting glass of high work function (indium tin oxide, ITO), photoconductivity will be observed. In the 1960s, semiconducting properties were observed in dyes particularly in methylene blue. Efficiency of 10 – 5 % in sunlight conversion was reported in the early 1970s to an improvement of 1 % in the early 1980s [4]. This was achieved through an interesting phenomenon known as hetero-junction. This phenomenon is a surface between semiconducting materials of dissimilar layers. Photovoltaic devices were applied with hetero-junction where donor-acceptor organic cells were tailored together. In recent years, photoconductivity has been measured in dyes and the dye solar cells have progressively been improved for laboratory cells. Currently power conversion efficiency of organic photovoltaic in single-junction devices is over 9 % and that of multi-junction cell is over 12 %[5].

1.3 Types of Organic Solar Cell

Organic Solar Cells can be classified into two essential sorts[6]:

1.3.1 Small-molecule OPV cells

Little molecule OPV cells utilize dyes with broad maintenance in the conspicuous and close infrared section of the electromagnetic Spectrum. Conjugated structures are consistently used for the electron-giving system, for instance, phthalocyanines, polyacenes and squarenes. Perylene hues and fullerenes are routinely used as the electron tolerating structures. These devices are most regularly delivered by methods for vacuum declaration to make bilayer and couple plans.

1.3.2 Polymer-based OPV cells

Polymer-based OPV cells utilize since quite a while ago anchored sub-atomic frameworks for the electron donating material (e.g., P3HT, MDMO-PPV), alongside derivatized fullerenes as the electron-tolerating framework (e.g., PC60BM, PC70BM). Like little atom OPV cells, these frameworks have little exciton diffusion lengths. Nonetheless, this confinement is dodged by a high interface surface territory inside the dynamic gadget.

1.4 Thesis Objective

The goal of this postulation is to study and investigation single layer and mass hetero-junction natural slim film photovoltaic cells.

For taking care of these, key semiconductor conditions like Poisson's equation, Schrodinger's condition, transporter progression condition, Drift-diffusion transport model, Fermi-dirac measurements and boltzman insights and so forth have been considered alongside physical model for light proliferation, optical profiles and so on. For our reproduction and structuring model reason, GPVDM has been utilized.

An itemized examination of natural semiconductors and their optoelectronic appropriate ties have been performed and from that investigation, an enhanced mass hetero-junction natural cell structure has been proposed. Likewise the issues looked amid the proposition works and the arrangement we found to those issues have been examined in a word in this theory.

Yields like short out current thickness (J_{sc}), open circuit voltage (V_{oc}), maximum control (P_m), greatest yield voltage (V_m), most extreme yield current (I_m), fill factors (FF), efficiency()for single layer and for mass heterojunction natural sunlight based cells have been reproduce and thought about for perception and examination.

Chapter 2

Photovoltaic Cell

2.1 Photovoltaic (PV) cell Fundamental Principle

The photovoltaic effect, the age of voltage when a gadget is presented to light, was found by Becquerel in 1839, in an intersection framed between a cathode and an electrolyte. From that point forward there had been reports of comparable effects on different strong state gadgets. The main photovoltaic effect of generous EMF voltage was seen by Ohl on a silicon p-n intersection in 1940. The photovoltaic effect on Ge was accounted for by Benzer in 1946 and by Pantchechnikoff in 1952. It was not until 1954 that the sun oriented cell got much expanded intrigue, started by crafted by Chapin et al. on single-precious stone silicon cells and of Reynolds et al. on Cadmium-sulfide (CdS) cells. Until now, sun based cells have been made in numerous different semiconductors, utilizing different gadget setups, and utilizing single-gem, poly-precious stone, and nebulous flimsy film structures. A sunlight based cell is like a photodiode. The photodiode can be worked in a photovoltaic mode, that is, it is unprejudiced and associated with a heap impedance like a sun based cell. Be that as it may, the gadget plans are on a very basic level different. For a photograph diode just a limited wavelength go focused at the optical sign wavelength is important, whereas for a sunlight based cell, wide phantom reaction over a wide sun based wavelength go is required. Photograph diodes are little to limit intersection capacitance, while sun powered cells are huge territory gadgets. A standout amongst the most significant figure of legitimacy for photograph diodes is the quantum efficiency, though the primary worry for sun based cells is the power transformation efficiency (control conveyed to the heap per occurrence sunlight based vitality [7]).

The sunlight based cell works in a few stages:

- Photons in daylight hit the sun oriented board and are consumed by semiconducting materials, for example, silicon.
- Electrons are energized from their current sub-atomic/nuclear orbital. When referred to an electron can either scatter the vitality as warmth and come back to its orbital or travel through the cell until it achieves a terminal. Flow moves through the material to drop the potential and this power is caught. The synthetic obligations of the material are indispensable for this procedure to work, and ordinarily silicon is utilized in two layers, one layer being fortified with boron, the different phosphorus. These layers have different synthetic electric charges and in this manner both drive and direct the flow of electrons.
- An cluster of sun oriented cells changes over sun powered vitality into a usable measure of direct flow (DC) power.
- An inverter can change over the ability to substituting current (AC).

2.2 Solar Radiation and Ideal Conversion Efficiency

The radiative vitality yield from the sun gets from an atomic combination response. In consistently about 6:2 10¹¹ kg of H₂, is changed over to He, with a net mass loss of around 4 10³ kg, which is changed over through the Einstein connection ($E = mc^2$) to 4 10²⁰ J. This vitality is discharged principally as electromagnetic radiation in the bright to infrared and radio ghostly ranges (0:2 to 3 m). The all out mass of the sun is presently around 2 10³⁰ kg, and a sensibly steady existence with an almost consistent radiative vitality yield more than 10 billion (10¹⁰) years is anticipated. The force of sun oriented radiation in free space at the normal separation of the earth from the sun has an estimation of 1; 353W=m². The climate weakens the daylight when it achieves the world's surface, mostly because of water-vapor retention in the infrared, ozone assimilation in the bright, and dissipating via airborne residue and pressurized canned products. How much the air affects the daylight got at the world's surface is evaluated by the air mass. The secant of the point between the sun and the zenith(sec) is characterized as the air mass (AM) number and it gauges the environmental way length with respect to the base way length when the sun is legitimately overhead. The AM0 subsequently speaks to the sun oriented range outside the world's air a value of 1; 353W=m²zenith, and the incident power is about 925W=m². The AM2 spectrum is for = 60° and has an incident power of about 691W=m², and so on.

Figure 2.1 shows the solar spectrums at various AM conditions. The upper curve is the AM0 condition which can be approximated by a 5; 800K black-body radiation, as shown by the dashed curve.

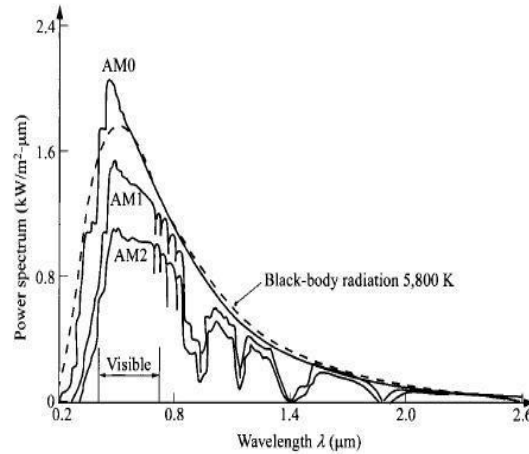


Figure 2.1: Solar spectrum at different air-mass conditions [8]

The AM0 spectrum is the relevant one for satellite and space-vehicle applications. The AM1.5 conditions (with sun at 45° above the horizon) represent a satisfactory energy-weighted average for terrestrial applications.

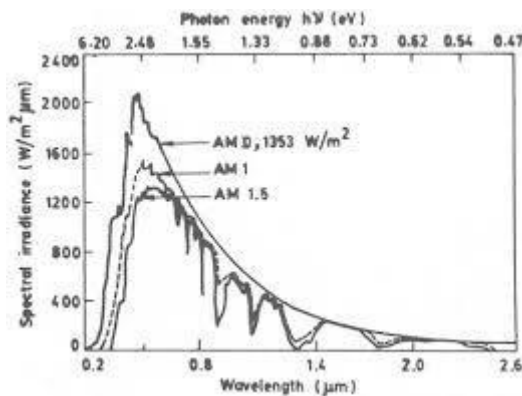


Figure 2.2: Solar spectrum in photon flux density per photon energy for AM0 and AM1.5 conditions[9]

For sun based cell vitality change, every photon creates an electron-gap pair, so the sunlight based power must be changed over to photon motion. The photon motion thickness per unit vitality for AM1.5 is appeared in figure 2.2 together with that for AM0. To change over wavelength to photon vitality, we utilize the relationship

$$= \frac{c}{\lambda} = \frac{1}{\lambda} \quad (2.1)$$

$$v = h \nu \text{ (eV)}$$

The total incident power for AM1:5 is 844 W/m^2 .

At the point when the cell is presented to the sun based range, a photon with vitality not exactly E_g makes no commitment to the cell yield (ignoring phonon helped ingestion). A photon with vitality more noteworthy than E_g contributes an electric charge to the cell yield, and the abundance vitality over E_g is squandered as warmth. To determine the perfect change efficiency, we will consider the vitality band of the semiconductor utilized. The solar cell is assumed to have ideal diode I-V characteristics.

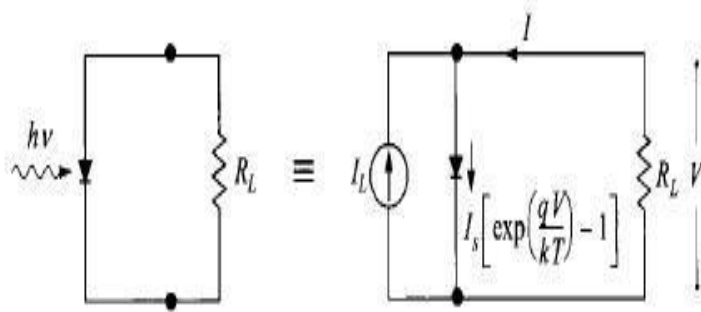


Figure 2.3: Idealized equivalent circuit of solar cell under illumination

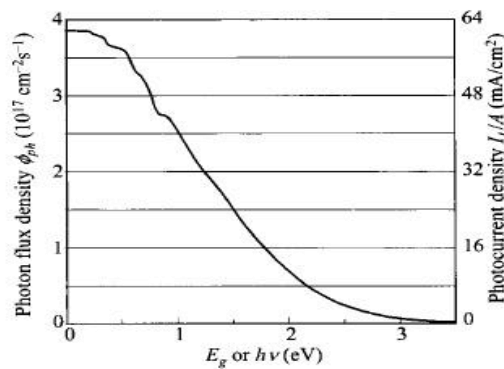
The equivalent circuit is shown in figure 2.3 where a constant-current source of photocurrent is in parallel with the junction. The source I_L , results from the excitation of excess carriers by solar radiation; and R_L is the load resistance. To obtain the photocurrent I_S we need to integrate the total area under the graph shown in figure 2.2, that is,

$$I_L(E_g) = Aq \int_{h=E_g}^{\infty} \frac{d\phi}{dh} dh \quad (2.2)$$

The result is shown in figure 2.4 as a function of the band-gap of the semiconductor. For the photo-current consideration, the smaller band-gap the better because more photons are collected.

The total I-V characteristics of such a device under illumination is simply a

Figure 2.4: Total number of photons in the solar spectrum (of AM1.5) above contributing to the maximum photocurrent specific E_g current and the photo-current, given as



photons in the solar spectrum above an energy value, maximum photocurrent specific E_g current and the photo-current

$$I_D = I_S \exp\left(\frac{kT}{qV}\right) - I_L \quad (2.3)$$

We obtain the open-circuit voltage by setting $I = 0$:

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_S + I_L}{I_S}\right) \quad (2.4)$$

2.3 Theory of I-V Characterization

PV cells can be modeled as a current source in parallel with a diode. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell, as illustrated in figure 2.5.

We review from past discourses in a perfect cell, the complete flow I is equivalent to the flow I_L created by the photoelectric effect less the diode flow I_D ,

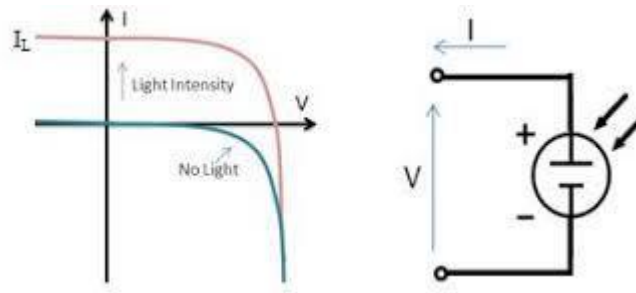


Figure 2.5: I-V Curve of PV Cell and Associated Electrical Diagram.

according to the equation:

$$I = I_L - I_D = I_L - I_S \left(\exp \left(\frac{qV}{kT} \right) - 1 \right) \quad (2.5)$$

Where I_S is the saturation current of the diode, q is the basic charge 1.6×10^{-19} Coulombs, k is a constant of significant worth 1.38×10^{-23} J/K, T is the cell temperature in Kelvin, and V is the intentional cell voltage that is either conveyed (control quadrant) or associated (voltage inclination). A continuously definite model will join two diode terms, regardless, we will concentrate on a lone diode model in this record.

Developing the condition gives the simplified circuit model showed up in figure 2.6 and the going with related condition, where n is the diode ideality factor (normally some place in the scope of 1 and 2), and R_S and R_{SH} addresses the series and shunt resistances that are depicted in further detail later in this area:

$$I_D = I_L - I_S \left[\exp \left(\frac{q(V + I.R_S)}{nkT} \right) - 1 \right] - \frac{V + I.R_S}{R_{SH}} \quad (2.6)$$

The I-V curve of an illuminated PV cell has the shape shown in figure 2.7 as the voltage across the measuring load is swept from zero to V_{OC} , and many performance parameters for the cell can be determined from this data, as described in the sections below.

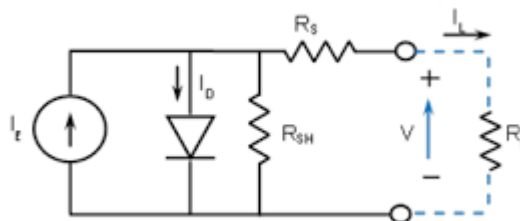


Figure 2.6: Simplified Equivalent Circuit Model for a Photovoltaic Cell
(Including Non-idealities)

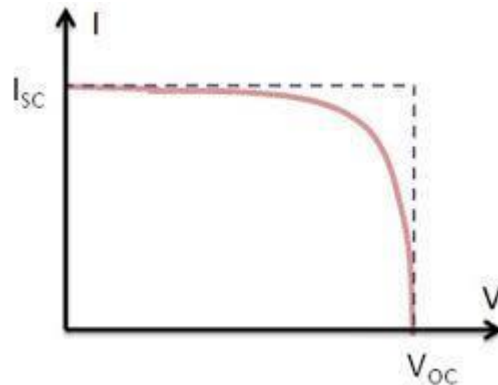


Figure 2.7: Illuminated I-V Sweep Curve

2.3.1 Short Circuit Current I_{sc}

The short out current I_{sc} analyzes to the short out condition when the impedance is low and is resolved when the voltage approaches 0.

$$I(\text{at } V = 0) = I_{sc}$$

I_{sc} occurs close to the beginning of the forward-tendency clear and is the most outrageous current motivator in the power quadrant. For an ideal cell, this most extraordinary current regard is the hard and fast current made in the sun controlled cell by photon excitation.

$I_{sc} = I_{MAX} = I_L$ for forward-inclination control quadrant.

2.3.2 Open Circuit Voltage V_{oc}

The open circuit voltage (V_{oc}) happens when there is no present going through the cell.

$$V(\text{at } I = 0) = V_{oc}$$

V_{oc} is additionally the most extreme voltage difference over the cell for a forward-predisposition clear in the power quadrant.

$$V_{oc} = V_{MAX}$$

for forward-bias power quadrant.

2.3.3 Maximum Power (P_{MAX}), Current at P_{MAX} (I_{MP}), Voltage at P_{MAX} (V_{MP})

The power made by the cell in Watts can be adequately decided along the I-V curve by the condition $P = IV$. At the ISC and VOC centers, the power will be zero and the most extraordinary impetus for power will occur between the two. The voltage and current at this most noteworthy power point are demonstrated as V_{MP} and I_{MP} independently.

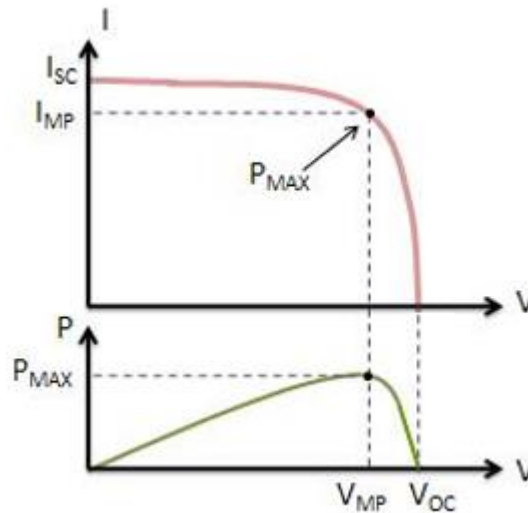


Figure 2.8: Maximum Power for an I-V Sweep

2.3.4 Fill Factor

The Fill Factor (FF) is basically a proportion of nature of the sun powered cell. Fill factor the proportion of most extreme reachable capacity to the result of the open-circuit voltage and short out current. Fill factor the proportion of light-touchy territory of a pixel to add up to pixel zone in a picture sensor. FF can likewise be deciphered graphically as the proportion of the rectangular regions portrayed in figure 2.

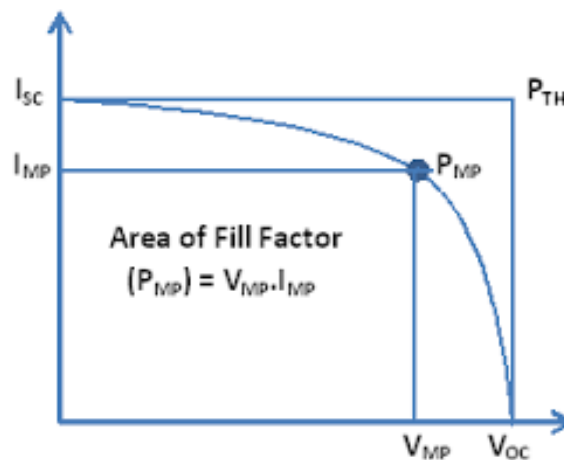


Figure 2.9: Getting the Fill Factor From the I-V Sweep.

A bigger fill factor is attractive, and relates to an I-V curve that is all the more square-like. A bigger fill factor is alluring, and compares to an I-V curve that is more square-like. Common fill factors range from 0.5 to 0.9. Fill factor is additionally a rate.

2.4 Efficiency

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. Terrestrial solar cells are measured under AM1.5 conditions and at a temperature of 25°C. Solar cells intended for space use are measured under AM0 conditions.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max} = V_{oc} I_{sc} FF$$

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}}$$

V_{oc} is the open-circuit voltage;
 I_{sc} is the short-circuit current;
 FF is the fill factor and
 η is the efficiency.

Stick is taken as the result of the irradiance of the episode light, estimated in W/m² or in suns (1000W/m²), with the surface region of the sun oriented cell (m²). The most extreme productivity (η_{MAX}) found from a light test isn't just a sign of the execution of the gadget under test, be that as it may, similar to the majority of the I-V parameters, can likewise be influenced by encompassing conditions, for example, temperature and the force and range of the episode light. Consequently, it is prescribed to test and think about PV cells utilizing comparable lighting and temperature conditions. Amid activity, the productivity of sun based cells is diminished by the dissemination of control crosswise over interior protections.

These parasitic insurances can be shown as a parallel shunt deterrent (RSH) and course of action resistance (RS), as depicted in figure 2.6. For a perfect cell, RSH would be endless and

would not give a substitute way for current to stream, while R_S would be zero, bringing about no further voltage drop prior to the heap.

Diminishing R_{SH} and expanding R_S will diminish the fill factor (FF) and P_{MAX} as appeared in figure 2.8. In the event that R_{SH} is diminished excessively.

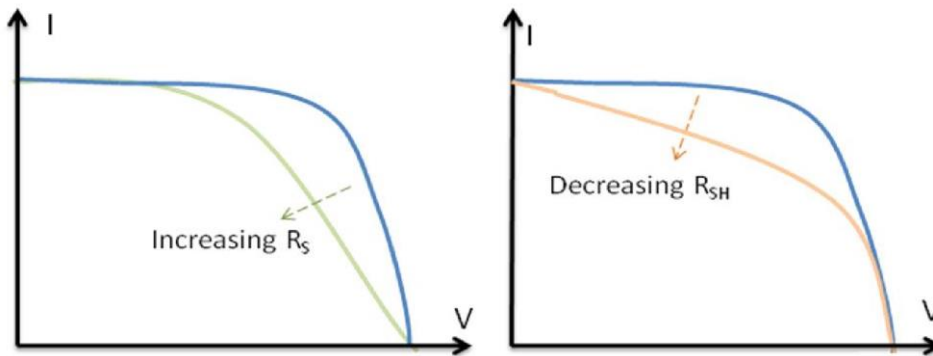


Figure 2.10: Effect of Diverging R_S & R_{SH} From Ideality

It is conceivable to estimate the arrangement and shunt protections, R_S and R_{SH} , from the inclines of the I-V bend at V_{OC} and I_{SC} , separately. The opposition at V_{OC} however, is, best case scenario relative to the arrangement obstruction yet it is bigger than the series obstruction. R_{SH} is spoken to by the incline at I_{SC} . Regularly, the resistances at I_{SC} and at V_{OC} will be estimated and noted, as appeared in figure 2.11.

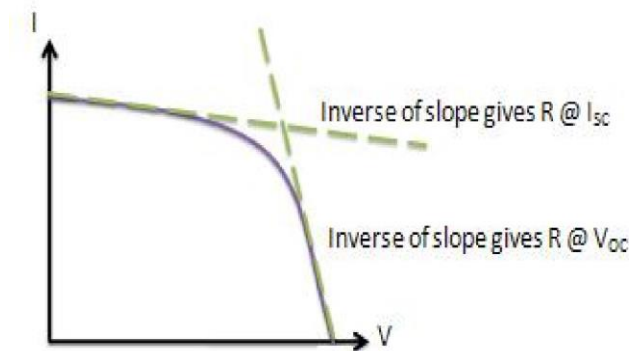


Figure 2.11: Obtaining Resistances from the I-V Curve

If scene light is kept from invigorating the daylight based cell, the I-V curve showed up in figure 2.12 can be obtained. This I-V twist is basically an impression of the "No Light" twist about the V-center point.

The grade of the immediate territory of the curve in the third quadrant (rearrange tendency) is a continuation of the straight region in the principle quadrant, which is the proportional straight locale used to register R_{SH} in figure 2.11.

It seeks after that RSH can be gotten from the I-V plot got with or without giving light excitation, despite when power is sourced to the cell. It is basic to note, regardless, that for certified cells, these securities are consistently a part of the light level, and can fluctuate in an impetus between the light and diminish tests.

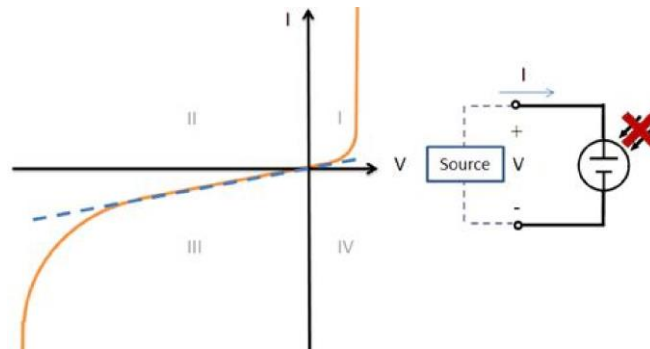


Figure 2.12: I-V Curve of Solar Cell Without Light Excitation

2.4.1 Temperature Measurement Considerations

The precious stones used to make PV cells, similar to all semiconductors, are delicate to temperature. Figure 2.13 delineates the effect of temperature on an I-V bend. At the point when a PV cell is presented to higher temperatures, ISC increments marginally, while VOC diminishes all the more significantly.

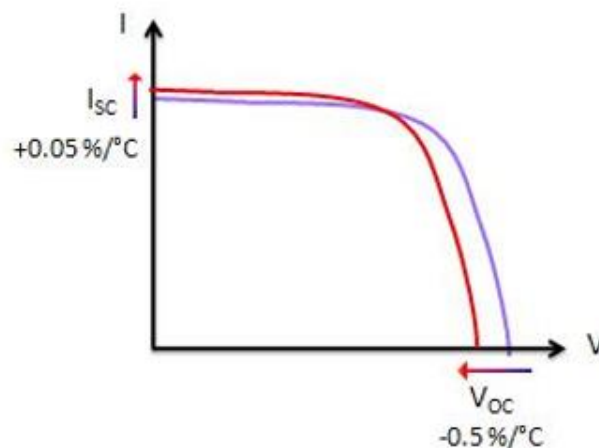


Figure 2.13: Temperature Effect on I-V Curve

2.4.2 I-V Curves for Modules

For a module or cluster of PV cells, the state of the I-V bend does not change. Nonetheless, it is scaled dependent on the quantity of cells associated in arrangement and in parallel. At the point when n is the quantity of cells associated in arrangement and m is the quantity of cells associated in parallel and I_{SC} and V_{OC} are values for individual cells, the I-V bend appeared in Figure 2.14 is created.

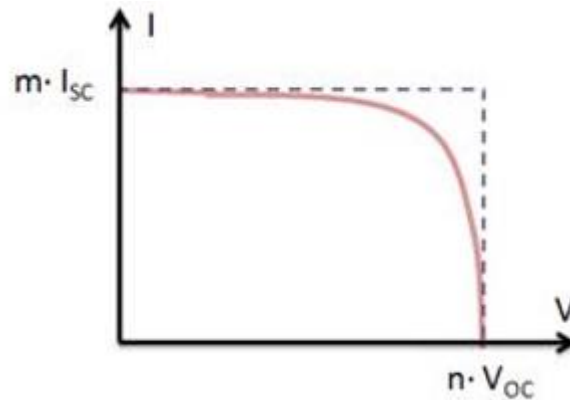


Figure 2.14: I-V Curve for Modules and Arrays

Chapter 3

Organic Photovoltaic Cell

3.1 Foundation and Basic Concept

Solar cell based Cell or Photovoltaic Cell(or PV cell in short), is the gadget that changes over the radiation of the sun to power. Each leaf of a green plant accomplishes something comparable they convert daylight to synthetic vitality. All things considered, a gathering of sun oriented cells, the alleged "natural cells", begun by acquiring the thought from the leaves. Arrangement handled mass hetero-junction sun based cells have increased some genuine considerations in most recent couple of years and are getting to be built up as one of things to come photovoltaic advances for least cost power production[10].To turn out to be industrially attainable, efficiencies somewhere in the range of 7 and 10%, and lifetimes of 5 to 7 years are essential. Meeting these difficulties requires a key knowledge in the one of a kind material science of natural sun based cells [11].

The atoms utilized in natural sunlight based cells are arrangement processable at high throughput and are shabby, bringing about low generation expenses to manufacture a vast volume [10]. The adaptability of natural atoms make the natural sun oriented cells conceivably cost effective for photovoltaic applications.

3.2 General Operation and Construction

TOrganic photovoltaic cells for the most part comprise of a benefactor and an acceptor. The contributor and acceptor must be produced using totally different materials.Each material has a characteristic HOMO (Highest occupied molecular orbital) and LUMO (lowest unoccupied molecular orbital) energy. In organic semiconductor physics, the HOMO takes the role of upper level of valence band while the LUMO serves as the lower energy level of conduction band. The energy separation between the HOMO and LUMO is defined as the band gap of organic electronic materials. This band gap is typically in the range of 1-4eV(electron Volts)[12]. Here the HOMO and LUMO of the donor are higher in energy than their respective counterparts in the acceptor.

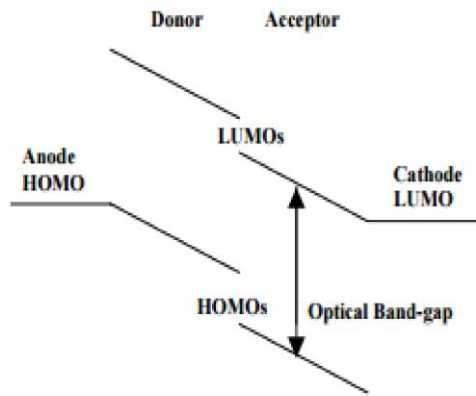


Figure 3.1: Energy band diagram of generic OPV consisting of donor and acceptor[11]

The opening between the HOMOs and the LUMOs are suggested as the optical band-gaps which are shown up in the figure 3.1. This optical band-gap chooses the base wavelength of light required for the excitation in each material. Photons hitting either supporter or acceptor particles invigorate an electron from the HOMO to the LUMO, yet this does not make a free electron-opening pair. This method rather conveys an immovably coupled electron-hole pair called an exciton. this is a result of the optical band-gap being more diminutive than the essentialness required to create a free electron-opening pair.

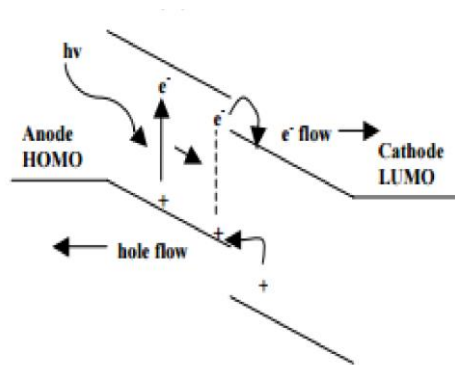


Figure 3.2: Small cell under illumination showing exciton formation, migration & dissociation[13]

So as to produce the free electron-opening pair, the exciton must go to the interface between the contributor and acceptor particles or between the natural atoms and the anode. At these intersections, electrons which have been eager to the LUMO can hop into the LUMO of the acceptor, while the gaps in the HOMO can bounce into the HOMO of the contributor. This reality is graphically spoken to in the figure 3.2. The separation can happen just if the difference in vitality between the HOMOs and LUMOs is more prominent than the coupling vitality of

the exciton. These stage isolated free electrons and openings at that point can relocate to their particular terminals. For efficient activity of natural sun based cells, it is required that the exciton needs to achieve an interface before a recombination happens. In PV cells, an effective field breaks the excitons into free electron-opening sets. This effective fields are set up by making hetero-intersection between two divergent materials. As communicated before the acceptor material has a conduction band edge that is lower than that of the shield material[14]. The entire procedure portrayed above is spoken to as stream diagram in the figure 3.3

The principle of operation utilizes conjugated and electron orbitals for light absorption, emission and charge generation and transportation of charges. Conju-gated system consists of an organic molecule that has alternative single and double bonds. Possible example of such bonds are seen in benzene and ethane. Generally

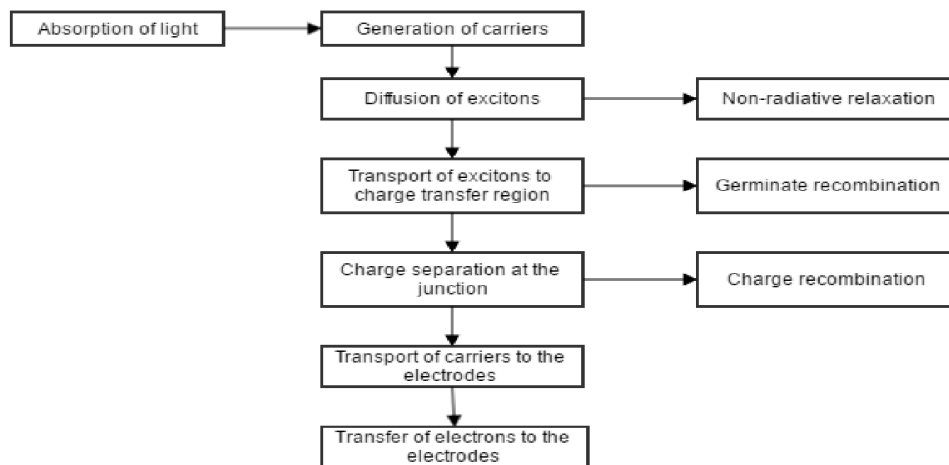


Figure 3.3: Conversion steps and loss mechanism of optical power to electrical power

electron has greater mobility than electrons, because they are able to move easily from one carbon atom to another carbon atom. There are two possible ways to draw benzene that shows high mobility of electron to move from one carbon atom to another atom. These two structures are visualized in the figure 3.4

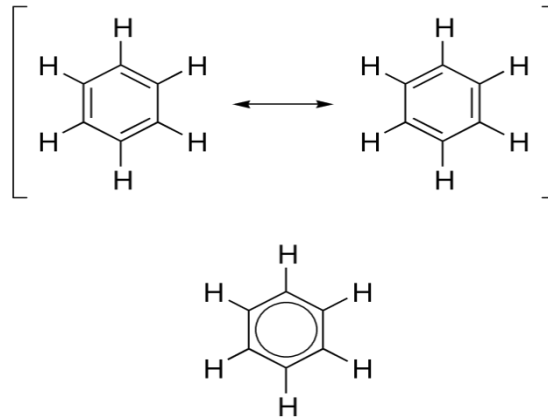


Figure 3.4: Structures of high mobility benzene ring

Sub-atomic material science of OPV can be closely resembling semiconductor material science [15]. There exists band hole between and electrons. What's more, is known as HOMO, though is knows as LUMO. Electron works for the most part for soundness of particle and isn't significant factor to consider for charge versatility. The procedure of charge photogeneration and transport in excitonic PV is appeared in figure 3.5.

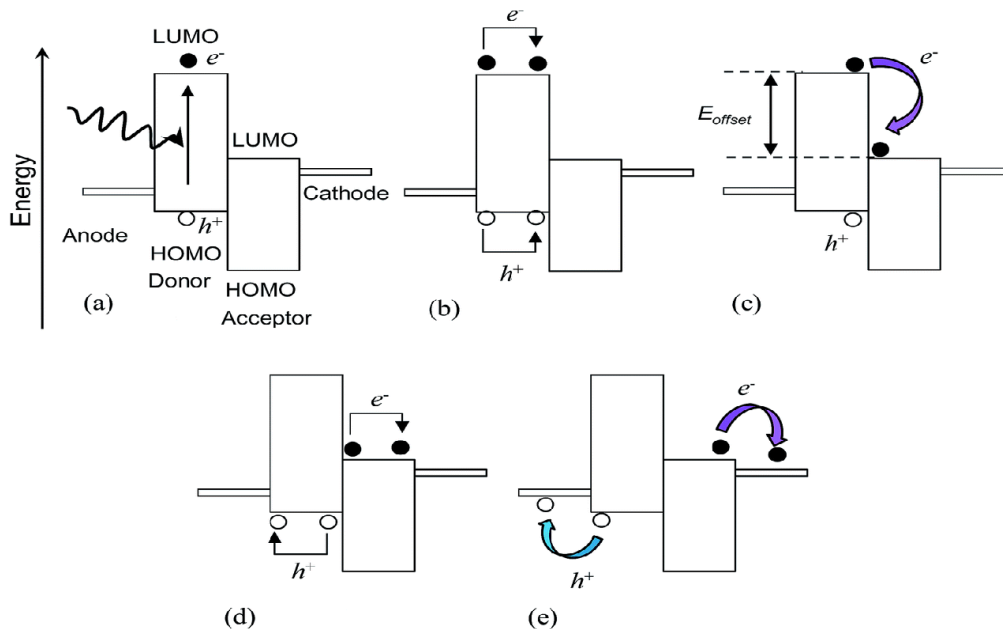


Figure 3.5: Processes responsible for photocurrent within photoactive donor/acceptor composites.

The procedures include light retention and pho-togeneration of an exciton (a). The last is trailed by exaction diffusion to the giver/acceptor interface (b), exciton separation (c), transport to the

photoactive layer/anode interface (d) and gathering of the charges by the cathodes (e) which moves the photogenerated charges to the outer circuit.

3.2.1 Prerequisite of Band Gap and HOMO-LUMO Energy Levels

The massiveness of the band opening and the centrality spots of the HOMO and LUMO importance levels are the most fundamental characteristics for picking the optical and electrical properties of a given conjugated polymer. These thusly sensationally influence a real photo voltaic execution. The concealed stage in the photo voltaic instrument which changes over light criticalness to electrical imperativeness in a contraption melds the help of sunlight by the photo dynamic materials. The wavelength of the maxi-mum photon advance thickness of the sun controlled range is arranged at around 700nm, which identifies with a low imperativeness of 1:77eV .To totally misuse the unending wellspring of daylight based significance, the ingestion degree of a conjugated polymer needs to cover both the red and close infrared compasses to empower a large portion of the terrestrial sun based range and thusly get the best photon improvement. It is exceedingly addressing make conjugated polymers with coherently wide ingestion through narrowing their optical band opening. To efficiently acclimatize light, high for the most part move coefficients of the polymers are in like manner of fundamental hugeness and should not be surrendered as the optical band gaps become humbler. The low band opening conjugated polymers have been positively considered for more than two decades to get a handle on a conclusive focal point of making common arranging metals without the need of doping. Through different controls and alterations of the compound structures of conjugated polymers, band openings as forlorn as 0:5eV can be created. While the utility of reasonable power source moves as a general issue to address the criticalness crisis, conjugated polymers with low band openings recover inspect essentialness as a result of their potential application in standard light based cells.

The most clear way to deal with oversee decay the band opening is on a very basic level by either raising the HOMO or cleaving down the LUMO estimation of the polymer or by crushing the two estimations closer together meanwhile. Heinously, the optical property related with light accumulating isn't the fundamental a single one under idea in coordinating new p-type polymers. Following photo excitation, the made exaction diffuses to the D-An interface to achieve charge bundle. To get high efficiencies from BHJ polymer sun based cells, the n-type material properties of the fullerene partners used should be viewed as all through the advancement structure. It has been demonstrated that the open-circuit voltage in BHJ daylight based cells with big-hearted mic contacts is straightly dependent on the degree of the undeniable potential, delineated as the difference between the HOMO estimation of a p-type polymer and the LUMO estimation of a n-type PCBM. The schematic criticalness profile and between related parameters of the supporter acceptor interface are showed up in figure 3.6. The supplier with the lower HOMO level will better go to the theoretically reachable VOC , in any case decline in a polymer's band opening to build up the upkeep union by lifting up the HOMO level will unavoidably result in lost VOC . Clearly, the LUMO estimation of p-type materials must be in any occasion 0:3eV higher than that segment of the fullerene subordinates to

guarantee the improvement of a declining basic primary purpose for the vivaciously positive electron trade and pulverization the coupling centrality of the intra-chain exciton.^{27,37,38} Lowering the LUMO estimation of a conjugated polymer to achieve a tight band opening may result in the LUMO level over the long haul being lower than that of the fullerene, along these lines hampering the efficient electron trade. A tradeoff is required to change the trade off between the little band opening of the promoter and the uncommon imperativeness HOMO-LUMO connection between the sponsor and acceptor. As such, the effort to find new p-type polymers for PSC isn't solely needed to scanning for after low band openings yet regardless of controlling the band gap by managing the HOMO-LUMO levels to their optimal traits.

3.3 Molecule Design

The plan and decision of efficient benefactor and acceptor particles is of incredible importance. As depicted in the past area, the applicant particle must have optical band-hole that is little enough to be energized by photon assimilation.

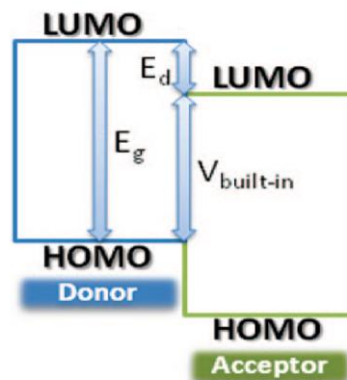


Figure 3.6: Energy diagram of supporter and acceptor HOMO-LUMO levels exhibiting three intercorrelated parameters. E_g is the band gap of the polymer, E_d is the LUMO essentialness difference impelling a declining central purpose for electron trade, and V_b is the worked in potential which has a straight relationship with the open-circuit voltage.

For all intents and purposes, the vast majority of the radiation occurs in the indisputable and infrared (IR) districts at wavelength extent of around 500nm, which identifies with the band gap of under 2.75eV. Provider particles should more likely than not settle opening vehicle and

acceptor molecules must allow electron transport. The mix of supporter and acceptor must be picked to consider the right offset between their HOMOs and LUMOs. Finally, the iotas must be functionalized in a manner with the objective that they can be solubilized for dealing with.

3.3.1 Donor Molecules

Supplier particles must satisfy a couple of essentials in order to work efficiently. Maintenance of photon in clear or IR light range is key for the difference in photons into excitons. After exciton improvement, the supporter molecule must allow the advancement of the exciton to the interface and moreover have sufficient difference in imperativeness band levels to allow exciton detachment. At the point when partition occurs, the opening must be offset as it moves back to the anode.

The maintenance spectra of normal particles in the UV-indisputable range are overwhelmed by the $\pi \rightarrow \pi^*$ advances of electrons. These advances occur in unsaturated blends and all things considered have very broad molar ingest when diverged from various advances such as $n \rightarrow \pi^*$,

$n \rightarrow \sigma$, $\sigma \rightarrow \sigma^*$. Various sorts of holding and adversaries of holding and relating changes are showed up in figure 3.7. The $\pi \rightarrow \pi^*$ transitions can be shifted from the UV to the visible by the inclusion

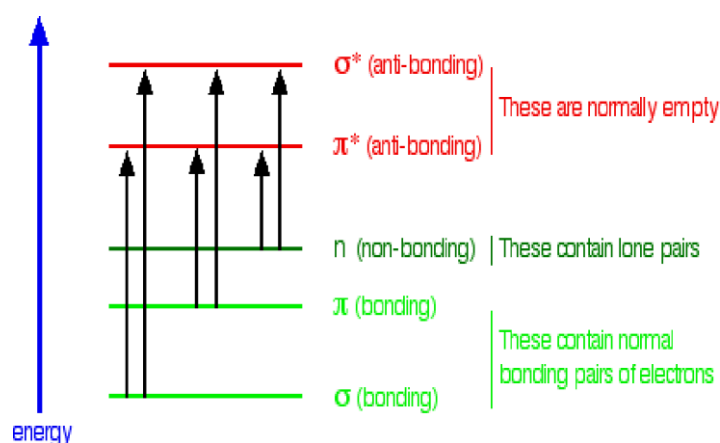


Figure 3.7: Various types of transitions and corresponding energy differences

of conjugated - bonds. Each new - bond includes another and comparing sub-atomic orbital. As more - bonds are included, the hole between the most noteworthy filled orbital (HOMO) and the most minimal unfilled - orbital (LUMO) contracts. This littler hole relates to a littler vitality (longer wavelengths) required for excitation. Therefore, polymers and natural little particles

utilized for photovoltaic are exceedingly conjugated to advance unmistakable light retention. The conjugated framework likewise takes into consideration the development of the two electrons and gaps along the atom by delocalization of those charges. Openings can be balanced out using electron giving gatherings.

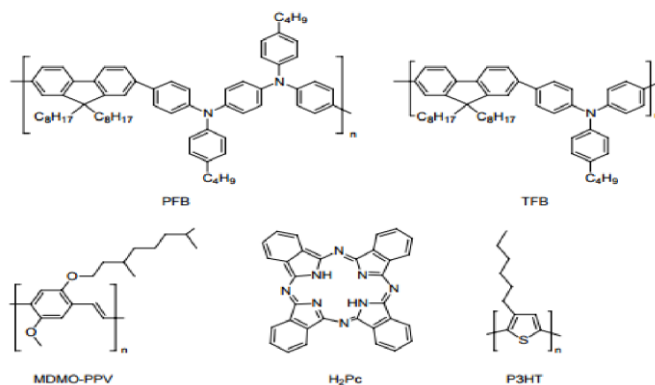


Figure 3.8: Examples of commonly used donor (p-type) polymers and small molecules: PFB, TFB, MDMO-PPV, H₂Pc, P₃HT

Few common donor molecules are shown in figure 3.8. Each molecule is highly conjugated and possesses electron-donating atoms such as oxygen, sulfur or nitrogen. In many cases, the donating heteroatom is also used as the site of attachment for long alkyl chains, which improve solubility [16].

3.3.2 Acceptor Molecules

Acceptor particles must meet a considerable lot of indistinguishable prerequisites from benefactor atoms concerning retention profiles, legitimate HOMO and LUMO collaborations and solvency. The major difference is the prerequisite that the acceptor atom balance out free electrons. This can be practiced in one of two different ways. Conjugated polymer chains can have electron-pulling back gatherings included, for example, CN or thiadiazoles or C₆₀ atoms, which have high electron affinity. Another significant point to consider is the cover of the assimilation profiles for the benefactor and acceptor particles.

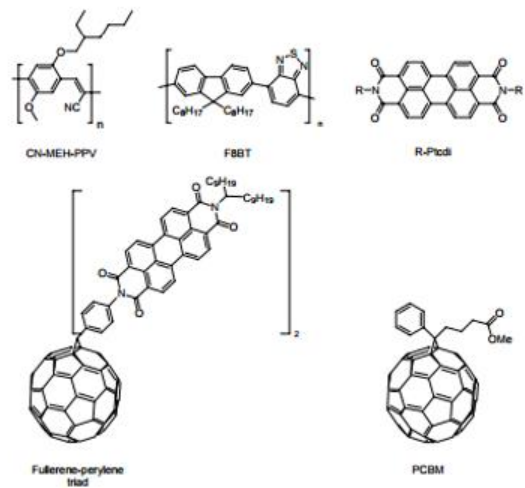


Figure 3.9: Examples of commonly used acceptor polymers and small molecules: CN-MEH-PPV, F8BT, R-Ptcdi,PCBM, Fullerene-perylene triad.

3.4 Basic OPV Cell Structure

Depending upon number of layers and junction types, organic photovoltaic cell can be divided into several categories. They are described briefly below:

3.4.1 Single Layer Cell

Single layer natural photovoltaic cells are the most straightforward structure. These sort of cells are made by sandwiching a layer of natural electronic material between two metallic channels as appeared in figure 3.10

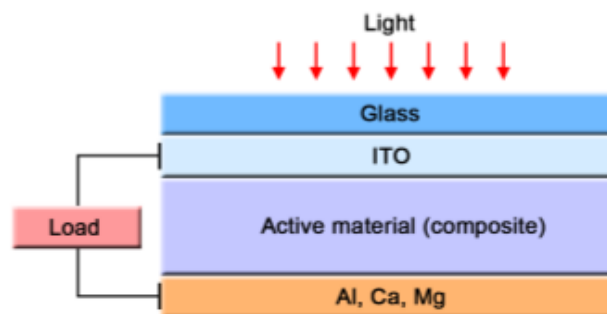


Figure 3.10: Structure of single layer OPV

Ordinarily, a layer of Indium tin oxide(ITO) with high work and a layer of low work limit metal like Aluminum or Calcium is used. This difference in work limit sets up an electric field in the common layer. Notwithstanding, single layer regular sun based cells don't work honorably in

light of having low quantum efficiency (< 1%) and low power change efficiency (< 0.1%). The recombination misfortune is additionally extremely high since charge particles travel in a similar material[17].

3.4.2 Double Layer Cell

Twofold layer natural photovoltaic cell contains two layers in the middle of the conductive terminals. The two layers have different electron affinity and ionization vitality, in this manner electrostatic powers are created at the interface between the two layers. A photovoltaic is created when the openings and electrons move to the comparing terminals by following either benefactor or acceptor phase (charge

extraction). Twofold layer PV cell structure is likewise called a planar benefactor acceptor heterojunction structure. A schematic structure of bilayer photovoltaic cell structure is appeared in figure 3.11. This sort of cell performs very well since charge has little likelihood to recombine when they are isolated. In any case, the diffusion length of excitons in natural electronic materials is ordinarily on the request of 10nm. All together for most excitons to diffuse to the interface and split into bearers, the layer thickness ought to be in a similar range as the diffusion length. In any case, a polymer layer routinely needs a thickness of in any occasion 100nm to ingest enough proportion of light. At such a huge thickness, just a little portion of the excitons can achieve the heterojunction interface.

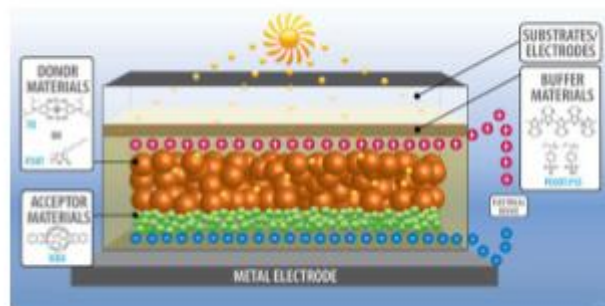


Figure 3.11: Typical Bi-layer PV cell structure[18]

3.4.3 Blend Cell

This sort of photovoltaic cells are made by interpenetrated system of contributor and acceptor materials. Henceforth, charge partition and transport is quick and simple as charge created can helpfully hop from giver material to adjacent acceptor material.

Discrete Hetero-junction

A three-layer(two acceptor and one contributor) without fullerene stack accomplished a transformation efficiency of around 8.4%. This usage created high open circuit voltages and

ingestion in the noticeable spectra and high short out flows. Likewise the quantum efficiency was above 75% somewhere in the range of 400nm and 720nm wavelengths, with an open-circuit voltage around 1V.

Bulk hetero-junctions Blend Cell

Bulk Hetero-junctions have an ingestion layer comprising of a nanoscale mix of benefactor and acceptor materials. The space sizes of this mix are on the request of nanometers, taking into consideration excitons with short lifetimes to achieve an interface and separate because of the huge contributor acceptor interfacial area[19]. Efficient mass hetero-intersection anyway need to keep up sufficiently enormous space sizes to shape a permeating system that enables the giver materials to achieve the gap transporting terminal and acceptor materials to achieve the electron transporting cathode. Without this percolating system, charges may be caught in a giver or acceptor rich area and experience recombination. This kind of hetero-junction structure has few focal points over layered structures since they can be made thick enough for effective photon assimilation

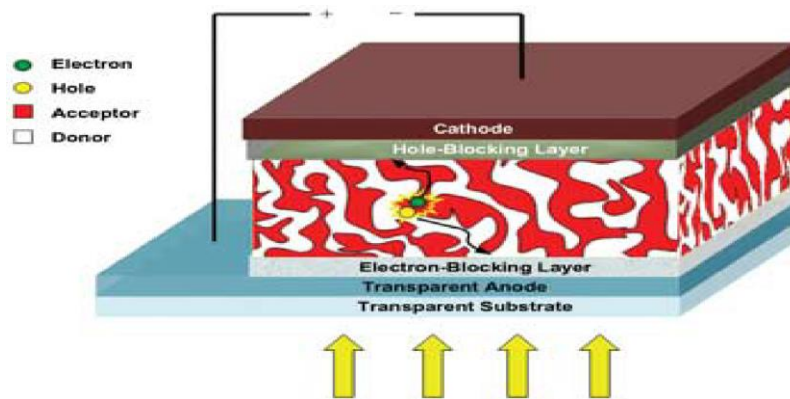


Figure 3.12: Organic Solar Cell made from bulk-hetero-junction formed by blending donor and acceptor, by: Guang Yong Li, Uni of Pittsburg

In the mass hetero-intersection cells the third segment, an auxiliary p-type giver polymer acts to retain light in a different locale of the sun based range. Hypothetically, this expands the measure of consumed light. In this way, these ternary cells work based on three particular instruments: charge move, vitality move or parallel-linkage. While moving charge, the two contributors contribute straightforwardly to the age of free charge transporters. Openings go through just a single contributor space before being gathered at the anode. Just a single benefactor produces openings and the subsequent contributor acts exclusively to retain light, and in this way moving additional vitality to the primary giver material [20]. A typical structure of bulk hetero-junction based organic solar cell is shown in figure 3.12

Graded Hetero-junction Cell

Another kind of hetero-junction cell is reviewed hetero-junction PV cell. There the electron giver and the acceptor are blended so that the angle is progressive. A cell with a mix of CuPC and C60 indicated quantum efficiency of around half and a power transformation efficiency of 2.1% utilizing 100 mW/cm².

Constant Junction

Like the reviewed hetero-intersection the consistent intersection idea goes for re-actualizing a steady progress from an electron contributor to an electron acceptor. However, the acceptor material is arranged straightforwardly from the giver polymer in a post-polymerization adjustment step [21].

3.5 Current Challenges and Recent Progress

Difficulties related with natural photovoltaic cells incorporate their low outer quantum efficiency (up to 70%) [5] contrasted with inorganic photovoltaic gadgets, regardless of having great inside quantum efficiency; this is expected to insufficient ingestion with dynamic layers on the request of 100nm. Insecurities against oxidation and decrease, recrystallization and temperature varieties can likewise prompt gadget debasement and diminished execution after some time. This strikes different degrees for gadgets with different organizations, and is a zone into which dynamic research is taking place[6]. Other significant components incorporate the exciton diffusion length, charge partition and charge gathering which are affected by the nearness of debasements.

3.5.1 Charge Carrier versatility and Transport

Particularly for mass hetero-intersection sunlight based cells, understanding charge bearer transport is indispensable in improving the efficiencies of natural photovoltaics. Right now, mass hetero-intersection gadgets have imbalanced charge-bearer versatility, with the gap mobility being in any event a request of greatness lower than that of the electron portability; this outcomes in space energize assemble and a diminishing in the fill factor and power conversation efficiency of a gadget. Due to having low versatility, efficient mass hetero-intersection photovoltaics must be planned with meager dynamic layers to stay away from recombination of the charge transporters, which is impeding to assimilation and adaptability in procedural. Recreations have shown that so as to have a mass hetero-intersection sun powered cell with a fill factor above 0.8

and outer quantum efficiency above 90%, there should be adjusted charge transporter portability to diminish a space charge effect, just as an expansion in control bearer versatility or potentially a decline in the bimolecular recombination rate constant[22].

3.6 Regular Polymer Used in OPV Cells

The materials commonly utilized as the dynamic layer of natural photovoltaic cells are recorded underneath.

3.6.1 Single Layer OPV cell dynamic layer materials

- C60 based Fullerene
- PEDOT:PSS
- P3HT (poly(3-hexylthiophene-2,5-diyl))
- CuPC (Copper phthalocyanine)
- APFO-Green 5
- Poly[9,9-didecanefluorene-alt-(bis-thienylene) benzothiadiazole]

3.6.2 Bulk-heterojunction OPV cell polymers

- P3HT.PCBM
- PTD7.PC71BM
- PCDTBT.PC60BM

3.7 Brief Description around couple of Polymers

3.7.1 Fluorene based copolymers

Lately a couple different polyfluorene copolymers were masterminded and attempted in solar cells. Polyfluorene is one of the most prominent polymers to be used as an active layer in the normal photovoltaic cells. This class of polymers offers a sufficient enormous vacillation in the circumstance of the HOMO/LUMO levels and polymers with a low bandgap showing a photosensitivity down to 1 m. Mass heterojunction sun controlled cells subject to blend of

fluorine polymers and PCBM were represented with an efficiency of 4.2% (AM1.5) revised for the ridiculous confuse). The outside and internal The external and inward quantum efficiency of these devices was found to have most extraordinary characteristics close 60% and 75%, A high open-circuit voltage is a typical part of fluorene-based polymer devices as the polymers consistently have a low-lying HOMO level et al. organized more than 10 different blends called APFO polymers.

3.7.2 Carbazole-Based Copolymers

Polymers reliant on 2,7-disubstituted carbazole have starting late happened to extraordinary eagerness as electron-giving materials in normal photovoltaic devices[23]. By virtue of the 2,7-carbazole homopolymer it has been found that electron acceptors other than fullerenes produce higher essentialness change efficiencies. The totally ladderised polymers gave poor results in devices, yet efficiencies of over 1% have been gotten from a phase ladder polymer with a diindenocarbazole monomer unit. Contributor acceptor copolymers containing 2,7-carbazole advocates and diverse electronaccepting comonomer units have been prepared. An efficiency of 6% has been represented from a device using such a copolymer and by fitting choice of the acceptor comonomer, polymers can be organized with potential speculative power change efficiencies of 10%.

3.7.3 Cyclopentadithiophene-Based Copolymers

Cyclopentadithiophene-based polymers have pulled in a great deal of consideration in the last few years. Six novel conjugated co-polymers (P1-P6) containing coplanar cyclopenta-dithiophene (CPDT) units (consolidated with bithiazole/thienyl-based monomers) were combined and created for the utilizations of polymer sun oriented cells (PSCs). Copolymers P1-P6 secured expansive retention ranges from UV to close infrared (400-800 nm) with thin optical band holes of 1.70-1.94 eV, which are good with the most extreme sunlight based photon reflux. Mostly reversible p and n-doping procedures of P1-P6 in electrochemical analyses were watched. Contrasted and those previously reported CPDT-based narrow band gap polymers, the proper molecular design for HOMO/LUMO dimensions of P1-P6 incited moderately high photovoltaic open-circuit voltages in the PSC gadgets [24].

Under 100mW/cm² of AM 1.5 white-light illumination, mass heterojunction PSC contraptions containing a working layer of electron supplier copolymers P1-P6 blended with electron acceptor [6,6]-phenyl C61 butyric destructive methyl ester (PCBM) in the weight extent of 1 : 1 were examined, and the external quantum efficiency (EQE) measure-ments exhibited a maximal quantum efficiency of 60%. The PSC device containing P4 in the weight extent of 1 : 2 with PCBM gave the best groundwork result with a general power change efficiency (PCE) of 3.04%, an open-circuit voltage of 0.70 V, a short out current of 8.00mA/cm², and a fill factor of 53.7%.

3.7.4 P3HT:PCBM

P3HT:PCBM or poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl C61-butyric corrosive methyl ester (PCBM) have made the most efficient natural photovoltaic cells up until this point. This is on the grounds that the attributes of P3HT:PCBM supports high solidness, high gap versatility, high crystallinity and ready to ingest wavelength up to around 650 nm. Moreover, C60 in PCBM is solid electron acceptor. Also, C60 empowers quick charge detachment. Besides, C60 is the most affordable and most vitality sparing fullerene. P3HT and PCBM structures are appeared in figure 3.13. The dynamic polymeric material is an admixture of P3HT, a p-type polymer, and PCBM, a n-type acceptor.

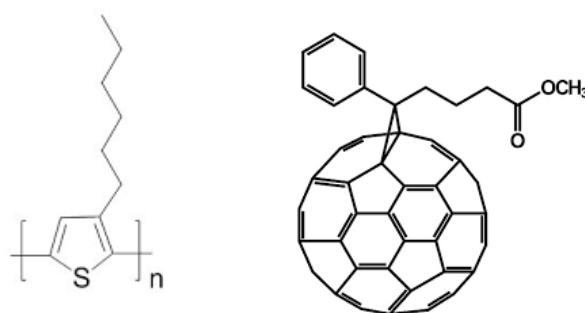


Figure 3.13: Structures of P3HT and PCBM

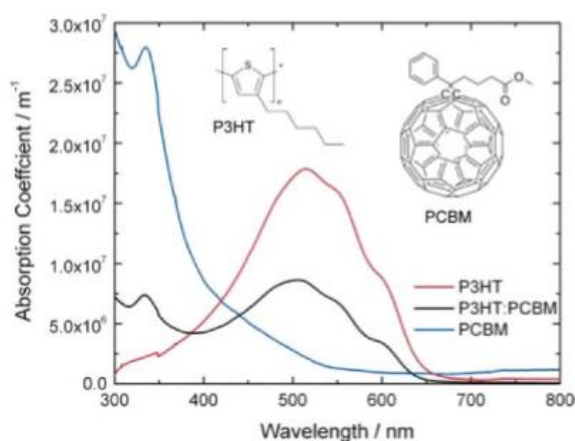


Figure 3.14: Absorption spectrum of P3HT:PCBM

The assimilation range of P3HT:PCBM polymer mass heterojunction is appeared in figure 3.14. For unadulterated P3HT film the strong state ingestion spectra indicated two crests at 493 nm and 517 nm and one shoulder at 572 nm. These three groups can be credited to the p-p* progress.

3.7.5 P3HT:PCBM under Thermal Annealing

A generous improvement in the PCE of P3HT:PCBM dependent on sun powered cells have been gotten by warm toughening. The principle effect of tempering is depicted as redistribution of fullerene separated particles of PCBM start to diffuse into bigger totals and in the PCBM free areas. The P3HT totals can be changed over into P3HT crystallites. Corresponding transport

thinestimationportabilitylifetimeitem($\mu\tau$)forthemajoritycarrierandattributestheefficiencygainand uetoannealingtothe reducesrecombinationlossesbyanoptimizedphase-structures morphology longside an expanded phantom photocurrent commitment in the close IR area. Also, warm strengthening makes a compositional slope over the P3HT:PCBM films, which upgrades the charge travel capacity significantly. These improved interfacial properties and efficiency in control travel capacity represent the better power transformation efficiency of P3HT:PCBM PSCs treated with warm strengthening [25].

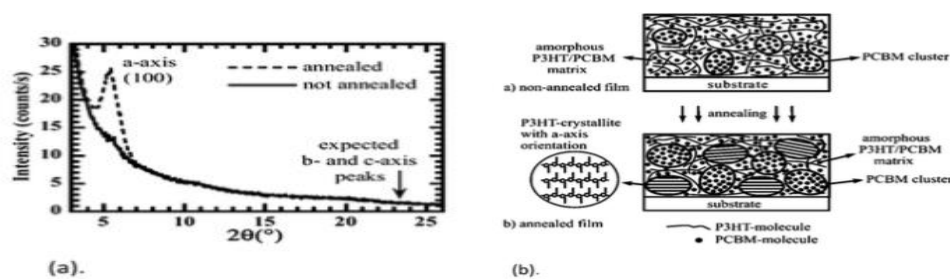


Figure 3.15: (a) Intensity vs temperature curve (b) The effect of Thermal Annealing on P3HT:PCBM

The effect of warm tempering is appeared in figure 3.15. The toughening of P3HT:PCBM composites changes the morphology and optical ingestion as well as even outcomes in changes in the redox and photoconductive properties of the mix layer. Aside from P3HT:PCBM some different frameworks, for example, PCPDTBT:PCBM and some other polymer-polymer based sun based cells have indicated higher PCE in the wake of strengthening.

3.8 Effect of interface in natural photovoltaics

Contingent upon the material framework utilized, the interface effects the accompanying actualities of a natural sun oriented cell:

- The open-circuit voltage (V_{oc})
- The Polarity of the gadget
- Light engendering and conveyance on account of optical spacer materials

- They physical, compound or ecological connection of the polymer and terminal
- The contact selectivity

3.8.1 Cause of *VOC*

The *VOC* starts from the difference of the most astounding involved sub-atomic orbital (HOMO) of the donor material and the lowest occupied molecular orbital (LUMO) of the acceptor material when these two materials are in thermal equilibrium. Interface materials may lessen the open circuit voltage yet it can't expand it past the HOMO-LUMO difference.

3.8.2 Assurance of Polarity-Inverted and Non-Inverted Structure

A mass heterojunction composite can be viewed as one trademark semiconductor with a high quantum efficiency for charge age. On the off chance that one can disregard vertical stage restriction between the fullerene and the polymer, such a composite does not have a particular going to expel electrons or openings. Everything considered, clearly the decision of the cathode and interface materials will pick the uttermost purpose of the contraption. The uttermost purpose of the sun energized cell is therefore compelled by the interface materials or much more unequivocally by the interface shaped between the supporter material at the anode and the acceptor material at the cathode.

3.9 Optical Spacer

For characteristic sun situated cells, expansion of an optical spacer between the dynamic layer and the reflective terminal results in a redistribution of the optical electric field. The most outrageous thickness and subsequently maintenance of the dynamic layer is given by the vehicle properties of the provider acceptor blend. Due to these vehicle confinements, the dynamic layer thickness of characteristic sun controlled cells is regularly more diminutive than a huge bit of the wavelength of the conspicuous light. In this thickness routine interface effects expect a noteworthy activity. For such optically slight structures, light is reflected at the nontransparent cathode and can pass the dynamic layer twice. The optical spacer is a thought that can construct the ingestion for shaky film structures. This is done by including a clear layer, ideally with a high refractive record, between the dynamic layer and the reflecting metal terminal. Normally, this pitiful and clear layer of around 10nm is adequate to significantly change the circumstance of the close-by maintenance generally outrageous. When best in class, such an optical spacer layer can help moving the breaking point of maintenance into the dynamic layer. We talk about the effect of two sorts of optical spacers in the going with zone.

3.9.1 ZnO as Optical Spacer

The ZnO layer used to improve the light-reaping expands the charge gathering efficiency, fills in as a blocking layer for openings, and lessens the recombination rate. The consolidated optical and electrical enhancements raise the power transformation efficiency of arrangement handled little atom sun based cells to 8.9%, that is, equivalent to that of polymer counterparts[26]. An outline of natural photovoltaic cell with ZnO as optical spacer is appeared in figure 3.16. The IV attributes is additionally appeared in the figure.

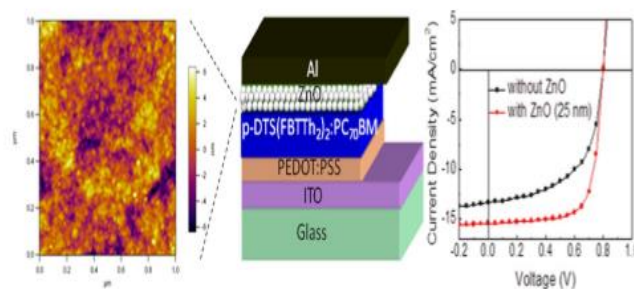


Figure 3.16: ZnO as Optical Spacer & I-V Characteristics

3.9.2 Arrangement based Titanium oxide as Optical Spacer

Titaniumdioxideisapromisingcandidateasanelectronacceptorand transport material, as confirmed by its utilization in color sharpened cells] mixture polymer/TiO₂ cells and multilayer Cu-phthalocyanine/color/TiO₂ cellsandmultilayerCu-phthalocyaninecells. Normally, be that as it may, crystalline TiO₂ cells and multilayer Cu-phthalocyanine is utilized, either in the anatase stage or the rutile stage, the two of which require treatment at temperatures (T < 450°C) that are conflicting with the gadget engineering appeared in figure 3.17; the polymer:C60 composite can't endure such high

temperatures. By presenting the TiO_x cells and multilayer Cu-phthalocyanine optical spacer, the polymer photovoltaic cells with power-change efficiency in expanded by roughly 50% [27].

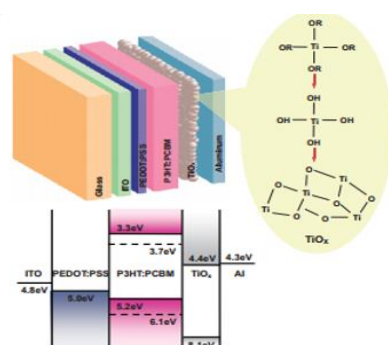


Figure 3.17: The chemical structure of TiO_x

The subsequent schematic portrayal of the spatial dispersion of the squared optical electrical field quality $|E|^2$ is appeared in figure 3.18

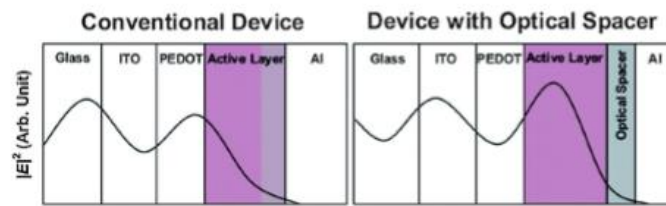


Figure 3.18: Spatial distribution of the squared optical electrical field strength

3.10 Interface Materials for OPV cell

A large portion of the interface materials are wide-bandgap semiconductors and the situation of their valence and conduction groups are with respect to that of the natural semiconductor might be sufficient to recognize a p-type and n-type contact.

3.10.1 p-doped Polymers

For polymer OPV cells PEDOT:PSS is broadly utilized. PEDOT:PSS frames a particular contact for gaps. It is the arrangement saved and has high straightforwardness. One of the options to PEDOT:PSS is a sulfonated poly(diphenylamine).

3.10.2 Jobs of Metal-oxide materials

The dynamic materials are responsible for the maintenance of light and photogeneration of charge bearers. Light devoured by the polymer and excitons is isolated at the interfaces with the metal oxide. Without an exciton partition interface (the oxide), free transporters are not created. Holes are then moved through the polymer the electrons through the oxide until they are accumulated at the cathodes.

Transparent electrodes

Normal semiconductors have commonly low conductivities and in this manner, photogenerated charge corners can just diffuse a couple of hundred nanometers before they recombine. Clear terminals are henceforth required, which can assemble charges over the entire contraption area while up 'til now empowering scene light to accomplish the dynamic layer. Wide bandgap change metal oxides are unfaltering materials for this application due to their extraordinary optical properties and the ability to their electrical properties through doping.[28].

Charge blocking Layers

One essential source of inefficiency in characteristic PV begins from dull current or spillage current. Charges implanted at the anodes recombine with photogenerated charges, henceforth diminishing contraction execution. Characteristic PV cells suffer from this issue explicitly in light of the blended thought of the dynamic layers, both p and n-type materials contact the two anodes. One way to deal with reduce the spillage current is to install metal oxide blocking layers on either side of the dynamic layer. Inferable from the difference in imperativeness level arranging, one layer underpins the vehicle. This embraces terminal selectivity and decreases the diminishing current.

Charge Collectors

Some metal oxides have commonly high mass electron mobility (hundreds of $\text{cm}^2 \text{V}^{-1} \text{s}^{-1}$, 3-4 solitations of size higher than that of various organics). Everything considered they can go about as charge experts in standard common PV devices. Normal or blend blends are intercalated into oxide nanostructures where the high portability nanowires connect into the dynamic layer and lead photogenerated charge transporters to tan anode.

Middle of the road Layers in Tandem cells

The most amazing efficiency inorganic PV contraptions contain different layers, with different band gaps stacked in a couple of plan (for instance GaInP/GaInAs/Ge). To accomplish this in a characteristic photovoltaic device, a widely appealing layer must be accessible for a couple of reasons. In the first place, this layer verifies the base cell and keeps it from the interminable supply of coming about cells. In addition, it comes to between different cells. Thirdly, it grants unfortunate electrons from one layer and unwanted holes from another to recombine; by and large, these recombine with the charges expected for extraction. This moderate layer can be contained two or three nanometers of metal oxide.

Stability Enhancers

Semiconducting polymers are commonly precarious within the sight of light and oxygen. It has been accounted for that oxygen deficient oxides like TiO_x ($x < 1.34$) can search for oxygen and in this way improve the dependability of the natural layer.

Cathode prerequisites for natural sun oriented cells

Like some other sun based cell, regular sun fueled cells require in any occasion one light-transmissive terminal. The subsequent anode can be cloudy or direct, which depends upon the specific application. The capability between the anode and cathode in bulk heterojunction normal photovoltaics isn't irrelevant due to mass heterojunction and depends solidly on the plan of the cell.

Terminal necessities for OPV cells are defined by the material properties and the coordinated effort with the semiconductor materials, yet moreover need to consider the similitude of move to-move taking care of, sufficient flexibility, incredible natural trustworthiness - all in blend with low material costs. Extra benefits are grabbed if the anode in like manner goes about as a limit against water or oxygen. It gives robustness in case it can square the UV part of the observable light. This the truth is analyzed in the importance of ohmic contacts for cutting edge daylight based cell execution and for characteristic semiconductors where HOMO and LUMO levels are regularly in the extent of 5.5 to 3.5eV. In the above case, the cathodes need to cover the band region.

3.11 Anode prerequisites for natural sunlight based cells

Like some other sunlight based cell, natural sun oriented cells require at any rate one light-transmissive cathode. The second cathode can be dark or straightforward, which relies upon the specific application. The refinement between the anode and cathode in bulk heterojunction natural photovoltaics isn't minor because of the idea of mass heterojunction and depends emphatically on the engineering of the phone. Anode prerequisites for OPV cells are defined by the material properties and the collaboration with the semiconductor materials, yet also need to consider the similarity of move to-move preparing, sufficient flexibility, great ecological solidness - all in the mix with low material expenses. Extra benefits are picked up if the cathode likewise goes about as an obstruction against water or oxygen. It gives dependability if it can square UV part of the obvious light. This reality is talked about in the significance of ohmic contacts for upgraded sun based cell execution and for natural semiconductors where HOMO and LUMO levels are regularly in the scope of 5.5 to 3.5eV. In the above case, the terminals need to cover the band district [29].

3.12 Materials for Transparent Electrodes

3.12.1 Indium Tin Oxide (ITO)

Indium tin oxide (ITO) is a ternary structure of indium, tin and oxygen in changing extents. Contingent upon the oxygen content, it can either be depicted as a fired or composite. Indium tin oxide is regularly experienced as an oxygen-soaked piece with a detailing of 74% In, 18% O₂, and 8% Sn by weight. The inherent work capacity of ITO is between 4.4-4.9 eV. The synthetic strength of ITO is sensible and can be additionally improved by doping with different materials. Tragically, exceptionally conductive ITO is likewise very crystalline, and all things considered, indicates rather high fragility. Another disadvantage of the high conductive ITO films are enormous crystallines, which bring on additional surface harshness. Be that as it may, the expense is another significant issue as one kilogram of ITO costs around 1000 US\$.

3.12.2 Other Type of Materials

Several emerging materials such as conducting polymers, carbon nanotubes, graphene, and metallic nanowires show potential as trades for sputtered ITO. Be that as it may, there are additionally difficulties for these new materials, for example, enormous sheet opposition in leading polymers, long haul security and high contact protections in carbon nanotubes and metallic nanowires, and huge scale creation in graphene. Subsequently, growing new materials join most attractive properties for straightforward terminals will fulfill the expanding interest for minimal effort flexible gadgets.[33].

Contrasted and inorganic materials, natural materials have a few focal points, including ease handling, mechanical flexibility, and expansive ghostly and vitality level tunabilities. An outstanding rising straightforward anode dependent on a natural material is poly(3,4-ethylenedioxythiophene) doped with polystyrene sulfonic corrosive (PEDOT:PSS). At first, PEDOT:PSS has only here and there been utilized as a solitary straightforward anode in natural optoelectronic gadgets on account of its constrained electrical properties (the sheet opposition of PEDOT:PSS is commonly 10^4 - $10^5 \Omega \text{ sq}^{-1}$). A while later, the conductivity of PEDOT:PSS can be upgraded by including a high-breaking point dissolvable, expanding the proportion of PEDOT. Be that as it may, the optoelectronic properties of PEDOT:PSS still have a hole with business ITO cathode ($\sim 10 \omega \text{ sq}^{-1}$, transmittance $> 85\%$), and should be improved to meet the prerequisites of optoelectronic gadgets.

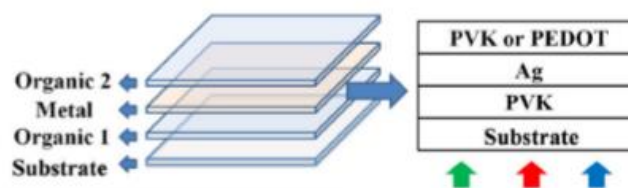


Figure 3.19: Structures of multilayer transparent electrodes based on organic materials. Studies have demonstrated that transmittance of a metal layer can be upgraded by embeddings a metal layer between two dielectric layers with reasonable refractive files. The transmittance and conductivity of a multilayer straightforward film dependent on a dielectric-metal-dielectric (DMD) structure can be advanced by tuning the thicknesses of the dielectric and metal layers to accomplish high straightforwardness in the noticeable district, just as high conductivity. Numerous inorganic semiconductors have been utilized as the dielectric materials in DMD straightforward cathodes that displayed aggressive properties in optoelectronic gadgets. Figure 3.19 demonstrates the materials and structure of the natural metal-natural (OMO) multilayer cathode [32].

Chapter 4

Comparative Study

4.1 Differences in structure and working standard of OPV and IPV

A large portion of the sun powered cells or photovoltaic cells utilized worldwide nowadays are siliconbased inorganic sunlight based cells (IPV). Natural photovoltaic cell(OPV) is yet to demonstrate its value in the pragmatic field as still now the efficiency of natural photovoltaic cell is extremely low contrasted with the inorganic ones. Be that as it may, for most recent couple of years, natural photovoltaic cells have much research consideration and the efficiency and other contributing components have significantly improved. In this section a relative investigation of natural photovoltaic cells with its inorganic partner is given and there are dialogs regarding for what reason to pick natural PV cells over inorganic PV cells.

Topic	Organic PV	Inorganic PV
Absorption of solar spectrum	Band-hole matches with absorbable sunlight based range effectively. A wide scope of photon's vitality range can be easily absorbed by OPV's dynamic layer. This natural property makes OPV quite preferred safeguard over IPV.	The ingestion range is substantially less wide than that of OPV. A designing methodology, for example, couple cells expands the scope of assimilation however it is still not upto the dimension of OPV. Also, so as to extend ingestion range, a various materials should be fell to respond to different specific parts of the sun based range. This, anyway makes two new issues (a) builds cost (b) most cases falling is ruined by "Crosssection.
Exciton Binding Energy	Exciton restricting vitality can be high as much as 0.5eV	Exciton restricting vitality is very low (in the request of few milli-eV). In this

	or more. But this can be solved by designing the concoction materials. This procedure requires the development of a Donor-Acceptor heterojunction to give interior electrochemical driving force to isolate e^- and h^+ .	way, separation of e^- and h^+ is easy. No additional instrument or material building is required.
Interfacial area	Interface between materials are important however much as could be expected because of low normal life-time of transporters (e^- and h^+). This low lifetime results in high recombination and therefore diminishing created accessible EHP. This is one of the primary reasons of lower efficiency.	Interface between materials are necessary yet not as much as OPV since the charge bearers have any longer lifetime. Essentially looking after the device length and changing doping - focus, transporter recombination can be brought down to an attractive dimension.

4.2 Motivations to pick OPV over IPV

The main reasons for which organic solar cells are preferable to inorganic solar cells are as below:

1. Low weight and flexibility of the PV modules.
2. Semi-straightforwardness.
3. Simple reconciliation into different items.
4. New market openings, for example wearable PV.
5. Significantly lower producing costs contrasted with ordinary inorganic advancements.
6. Assembling of OPV in a nonstop procedure utilizing best in class printing instruments.
7. Short vitality restitution times and low ecological effect amid assembling and activities.
8. To moderate the possibility of a world ruled by flat boards and ambiguously evil sunlight based collector towers particularly sun oriented power concentrator (SPC).
9. Adjust to all surfaces and lessen creation costs.

10. Light, translucent and sensitive to low light levels, photovoltaic solar cells open a totally different scope of potential outcomes which customary sunlight based cells can't offer.

11. The natural sun based cells have a comparative capacity however their engineering is multiple times more slender (about 100nm), mixing different layers of natural materials and semiconductors.

4.3 Weaknesses of Organic Photovoltaic Cell

Although there are many probable and currently available promising characteristics of OPV, the short-comings should be always kept in focus to surpass IPV. Some of the major limitations are following:

1. To accomplish high efficiency exciton should be isolated to $e^- h^+$ (EHP: Electron-Hole pair) at the earliest opportunity and conveyed to anode before recombination. This procedure calls for very unadulterated substance segments that expansion cost.
2. Another measure required to convey more EHP to anode before recombination is to make terminals structured in all respects thickly and increment interfacial region between consistently mixed materials. This procedure is still on advancement. A sufficient measure of effort (cost and generation time) is as yet required to accomplish an agreeable mixing.
3. Our silicon technology or IPV is on the leading edge of refinement and progress. So, widespread OPV manufacturing labs and technologies are yet lagging behind.

4.4 Remarks on OPV cells' future

1. Innovation is growing for effectively blending OPV. On the off chance that we can make an essential dimension of mechanical headway, research facilities and assembling instruments for structuring and testing OPV cells, the development in this industry will soar without a doubt.

2. OPV cell as of now wins in the assorted variety and usefulness race with IPV cell. Modest accessibility of OPV cells alongside its diversified functionalities will beat the foundation of IPV cells effectively.

3. Most importantly, it is the beginning of new time of innovation that may bring us most efficient vitality change like "Bio-glow (for example fire-fly)".

Chapter 5

Simulation Results and Conversation

5.1 Simulation Output from Single Layer OSC

We designed and simulated organic solar cell models using the GPVDM software varying the material type, layer thickness, type & number of active layer etc. The simulation outputs and various calculated values obtained from the simulation has been discussed in this chapter.

5.1.1 C-60 based Fullerene as Active Layer

Firstly, we simulated a single layer organic solar cell using C-60 based Fullerene as the active layer. The maximum power output (P_{max}), open circuit voltage (V_{oc}), Output current density for short circuit conditions (J_{sc}), the fill factor (FF), efficiency (η) parameters for different layer thicknesses are tabulated below in table 5.1

Table 5.1: Data for C-60 based Fullerene as Active Layer η

No of obs.	Thickness of active layer m	P_{max} W/m²	V_{oc} V	J_{sc} A/m²	Fill Factor	Efficiency %
1	2.2e-09	56.45	0.665	-120.25	0.687	5.54
2	1.8e-07	41.72	0.602	-98.31	0.701	4.90

5.1.2 PEDOT: PSS as Active Layer

Using PEDOT:PSS as active layer, the following data is found in table 5.2. Here, PEDOT:PSS means poly(3,4-ethylenedioxythiophene): poly (styrene sulfonate).

Table 5.2: Data for PEDOT:PSS as Active Layer

No of obs.	Thickness of active layer m	P_{max} W/m²	V_{oc} V	J_{sc} A/m²	Fill Factor	Efficiency %
1	2.2e-07	9.12	0.792	-10.72	0.835	8.90
2	1.e-07	11.34	0.845	-11.66	0.783	9.30

5.1.3 CuPC as Active Layer

Using CuPC (Copper phthalocyanine) as active layer the output efficiency is found to be 3.90%

5.1.4 P3HT (poly(3-hexylthiophene-2,5-diyl) as Active Layer

Organic photovoltaic cell with P3HT (poly(3-hexylthiophene-2,5-diyl) as single active layer gives the following data in table 5.3.

Table 5.3: Data for P3HT as Active Layer

No of obs.	Thickness of active layer m	P_{max} W/m²	V_{oc} V	J_{sc} A/m²	Fill Factor	Efficiency %
1	1e-07	60.4	0.625	-125	0.757	6.18
2	1.e-07	53.43	0.601	-115	.732	5.44

In this way, we find that P3HT can be utilized as dynamic layer to pick up the greatest power change efficiency. A representative schematic chart of P3HT as dynamic layer of a solitary layer natural sunlight based cell is appeared in figure 5.1. Here, Indium Tin Oxide(ITO) and the Aluminium(Al) are utilized as dynamic layer with 100nm thickness. For a solitary particle or polymers, we have utilized four(4) sorts of atoms. Here this outline creates the most astounding efficient OPV cell for P3HT.

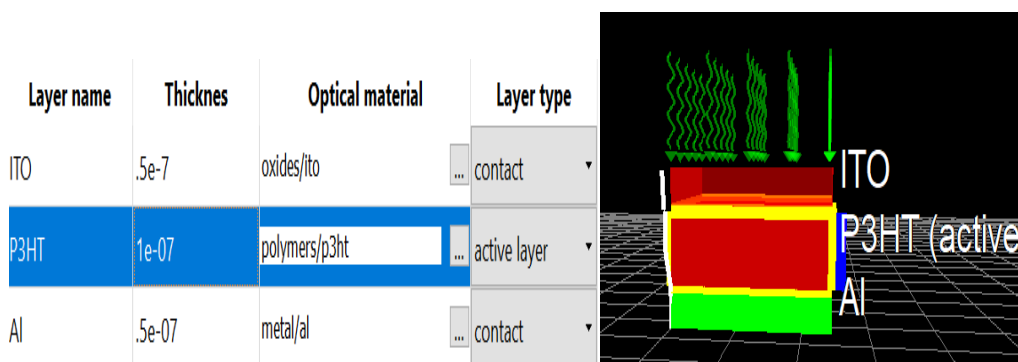


Figure 5.1: Schematic structure of single layer organic solar cell with ITO as top electrode, P3HT as active layer & Al as the bottom electrode

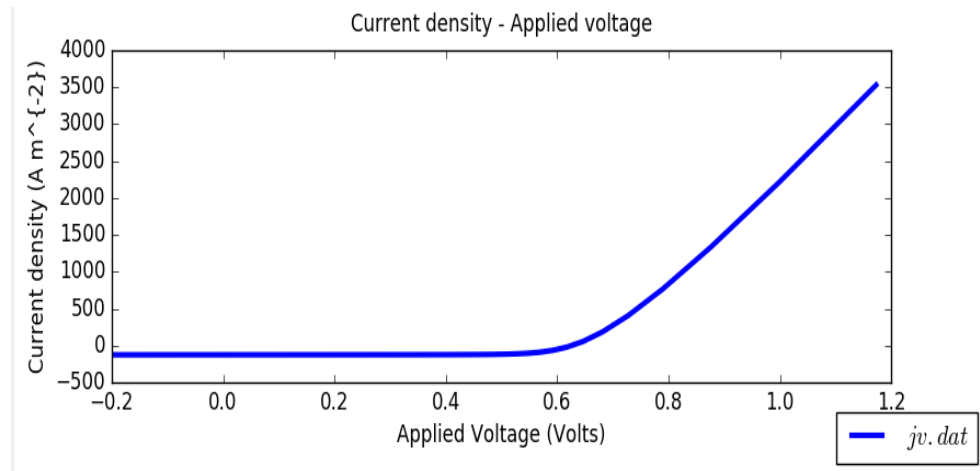


Figure 5.2: I-V characteristics curve of P3HT single layer cell

What's more, the comparing I-V attributes bend is appeared in figure 5.2. Current created for photon irradiance are drawn against voltage. By and large photovoltaic cell works in fourth quadrant where V is certain and I is negative. So absolute yield control is negative. As a matter of fact sun oriented cells work in photovoltaic mode.

The photon ingestion thickness is appeared in figure 5.3. Here photon ingestion thickness in different layers are appeared. We see that photon thickness increments with the difference in layers from ITO to dynamic layers since vitality of this dynamic layer is higher and most photons are caught up in this layer.

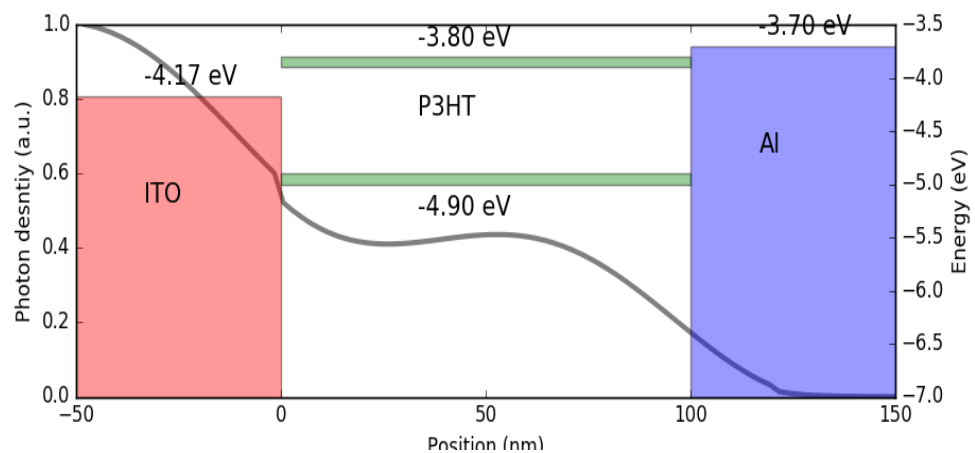


Figure 5.3: Photon Absorption Density of P3HT single layer cell

We know whether the photon retention thickness is greatest in the dynamic layer then the efficiency of the natural photovoltaic cell will be higher. The photon dispersion ingestion at different layer (for P3HT as dynamic layer) is appeared in figure 5.4. No light can achieve the last layer of Al. Thusly this plan is efficient structure, on the grounds that the vast majority of

the photons are caught up in dynamic layer and more electron gap sets (exciton) are created to expand efficiency.

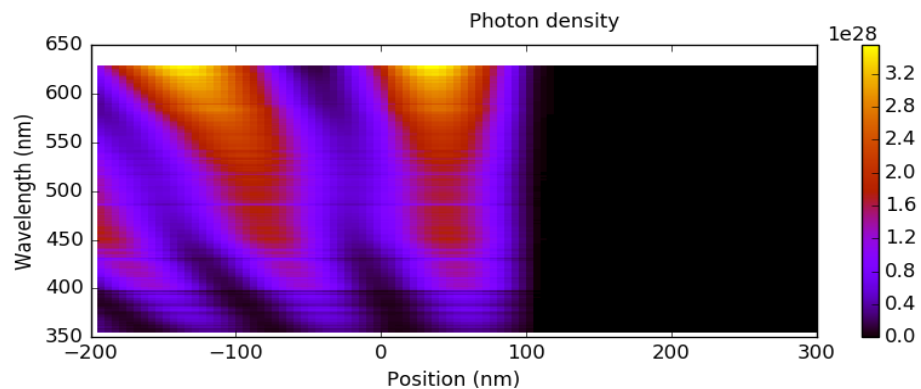


Figure 5.4: Photon Absorption at different stage of P3HT single layer cell

5.2 Simulation Output for Bulk hetero-junction OSC

Here, Contact on upper side to the light: ITO (Indium Tin Oxide).

Contact on lower side: Al (aluminum).

Size of the contacts: 100nm.

5.2.1 P3HT.PCBM as active Layer

P3HT stands for poly(3-hexylthiophene-2,5-diyl) and PCBM is the short form of phenyl-butyric acid methyl ester. We varied the active layer (P3HT:PCBM) thick-ness and simulated the structure. Table 5.4 shows the various data like maximum power output (P_{max}), open circuit voltage (V_{oc}), Output current density for short circuit conditions (J_{sc}), the fill factor (FF), efficiency (η) for this material.

Table 5.4: Data for P3HT.PCBM as Active Layer

No of obs.	Thickness of active layer m	P_{max} W/m²	V_{oc} V	J_{sc} A/m²	Fill Factor	Efficiency %
1	2.2e-07	50.03	0.605	-123.91	0.661	5.10
2	1.e-07	47.48	0.620	-105.45	0.761	4.95

3	1.1e-08	64.5	0.632	-138.5	0.732	6.10
4	1.5e-07	65.34	0.665	-145.4	0.745	6.78

We find here, when P3HT.PCBM blend is used as active layer, efficiency of organic solar cell is highest for 100nm thickness of the active layer.

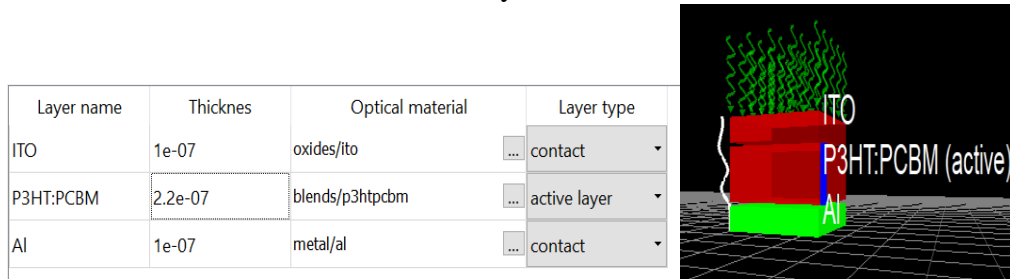


Figure 5.5: Schematic structure of bulk hetero-junction blend organic solar cell with ITO as top electrode, P3HT.PCBM as active layer & Al as the bottom electrode.

A schematic portrayal of the natural photovoltaic cell created by utilizing the P3HT.PCBM as dynamic layer (with 100nm thickness) is appeared in figure 5.6 which has the most noteworthy efficiency among different models of P3HT:PCBM with different thicknesses

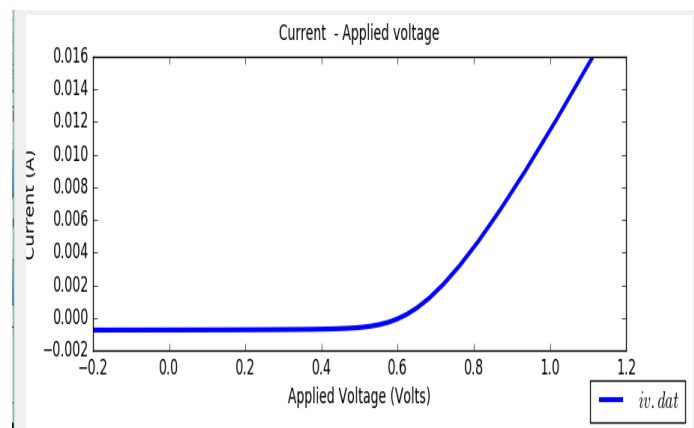


Figure 5.6: I-V characteristics curve of P3HT.PCBM blend organic cell

The IV characteristics for the above structure is shown in figure 5.6. Current generated for photon irradiance are drawn against voltage.

The figure 5.7 shows the photon absorption density for the organic photovoltaic cell whose structure is shown above in figure 5.5. Photon absorption at different

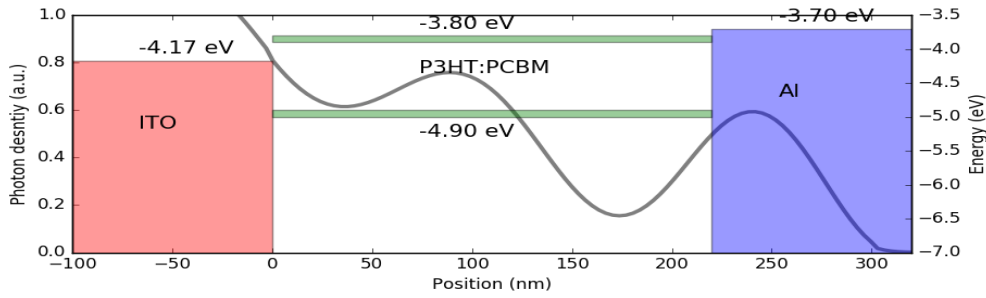


Figure 5.7: Photon Absorption Density of P3HT.PCBM blend organic cell

layer of structure is shown in this figure. Energy in active layers of P3HT:PCBM is higher than that of the transparent layer ITO. So, there is a rise in photon absorption when the layers change.

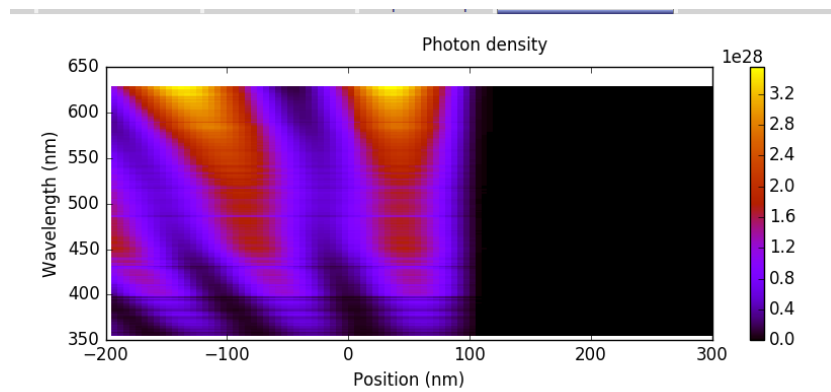


Figure 5.8: Photon Absorption Distribution of P3HT.PCBM blend organic cell

5.2.2 PTD7.PC71BM as Active Layer

We have done simulation with PTD7.PC71BM serving as active layer. With 0.9×10^{-7} m thickness, it renders an efficiency of only 6:55%. It is less than P3HT.PCBM. With 1.7×10^{-7} m thickness, efficiency decreases to 5:63%.

5.2.3 PCDTBT.PC60BM as Active Layer

With 1×10^{-9} m active layer of this material, efficiency decreases more to 5:00%.

So, P3HT:PCBM is the best option as bulk or blend material to use in organic solar cells when the contacts are of 1×10^{-9} m thickness.

5.3 Simulation Output after changing contact sizes

When contact sizes are reduced we found an increase in efficiency. Now, contact or electrode on upper side: Ag (Silver).

Contact on lower side: Al.

Size of the contacts: 50nm.

5.3.1 PCDTBT: PC70BM as Active Layer

Whenever PCDTBT: PC70BM (Here, PCDTBT represents Poly[[9-(1-octylnonyl)- 9H-carbazole-2,7-diyl]-2,5-thiophenediyl-2,1,3-benzothiadiazole-4,7-diyl-2,5-thiophenediyl] and PC70BM implies [6,6]-Phenyl-C71-butyric corrosive methyl ester) is utilized as dynamic layer, following outcomes are acquired for three different thickness. The information are appeared table 5.5.

No of obs.	Thickness of active layer nm	P_{max} $W=m^2$	V_{oc} V	J_{sc} $A=m^2$	Fill Factor	Efficiency %
1	100	122.5	0.567	-278.1	0.65	12.12
2	150	132.7	0.793	-302.12	0.79	14.32
3	200	111.3	0.622	-245.45	0.70	11.09

5.3.2 PBDTTT: PDI as Active Layer

The full name of PBDTTT is Poly[4,8-bis(5-(2-ethylhexyl)thiophen-2-yl)benzo[1,2-b;4,5-b']dithiophene-2,6-diyl-alt-(4-(2-ethylhexyl)- 3-fluorothieno[3,4-b]thiophene)- 2-carboxylate-2,6-diyl]] and the full type of PDI is A perylene diimide. Whenever PBDTTT: PDI fills in as dynamic layer, following outcomes in table 5.6 are acquired.

No of obs.	Thickness of active layer nm	P_{max} $W=m^2$	V_{oc} V	J_{sc} $A=m^2$	Fill Factor	Efficiency %
1	100	148.2	0.657	-333.15	0.67	14.123
2	150	114.56	0.669	-290.76	0.71	12.09
3	200	111.6	0.647	-270.15	0.62	11.45

5.3.3PBDTTT: PDI60 as Active Layer

When PBDTTT: PDI60 is used as active layer for the bulk-heterojunction organic photovoltaic cell, following data for maximum power, open circuit voltage, short circuit current, efficiency and fill factor are obtained in table 5.7.

Table 5.7: Data for PBDTTT: PDI60 as Active Layer

No of obs.	Thickness of active layer nm	P_{max} $W=m^2$	V_{oc} V	J_{sc} $A=m^2$	Fill Factor	Efficiency %
1	100	120.3	0.657	-233.33	0.69	12.51
2	150	164.5	0.823	-400.12	0.62	15.78
3	200	140.5	0.712	-378.45	0.75	13.67

So highest power conversion efficiency has been increased when PBDTTT: PDI60 with thickness of 150nm is used as the active layer.

A schematic structure of the bulk-heterojunction blend OPV cell with PB-DTTT:PDI60 as the active layer is shown in figure 5.9. Here the transparent

Layer name	Thicknes	Optical material	Layer type
ITO	1e-07	oxides/ito	contact
PBDTTT_PD160	1e-07	blends/pif8bt_pdi	active layer
layer2	1.5e-07	polymers/p3ht	active layer
Al	1e-07	metal/al	contact

Figure 5.9: Schematic structure of bulk-heterojunction blend organic solar cell with ITO as top electrode, PBDTTT: PDI60 as active layer & Al as the bottom electrode trode is Silver()Ag and the bottom electrode is (Al). The thickness of the active layer is shown to be 150nm.

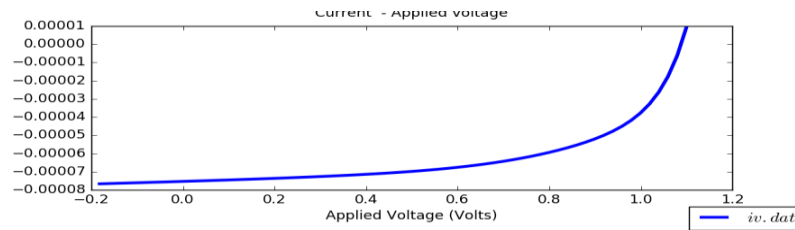


Figure 5.10: I-V characteristics curve of PBDTTT: PDI60 blend organic cell

The IV characteritition curve for the above structure is given in figure 5.10. As we can see from the figure, the curve is quite linear in a certain region.

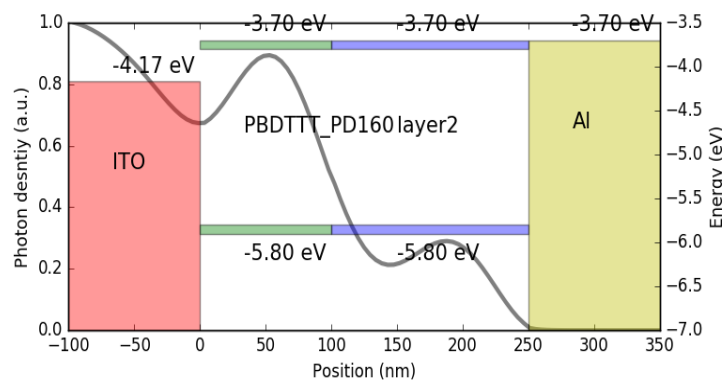


Figure 5.11: Photon Absorption Density of PBDTTT: PDI60 blend organic cell

Figure 5.11 demonstrates the photon ingestion thickness for the mass heterojunction OPV structure with PBDTTT:PDI60 as dynamic layer. Since vitality of Ag layer is higher than dynamic layer, a large portion of the photons are caught up in this layer. In this way, standardized worth reductions from 1 to 0.08 at that point rises little when photons go into the dynamic layer locale.

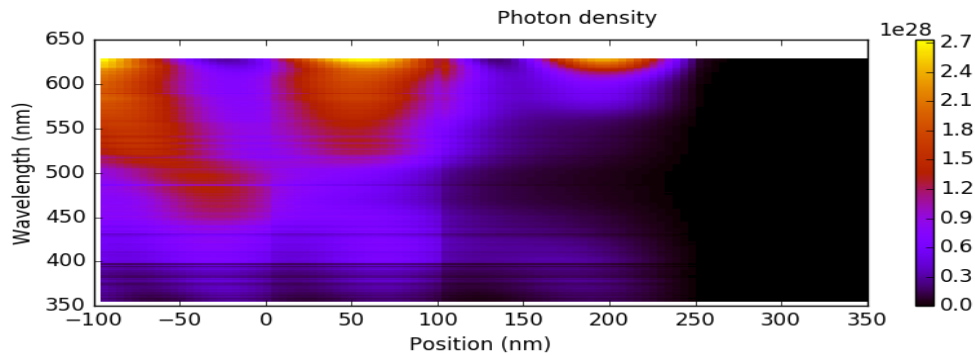


Figure 5.12: Photon Absorption Distribution of PBDTTT: PDI60 blend organic cell

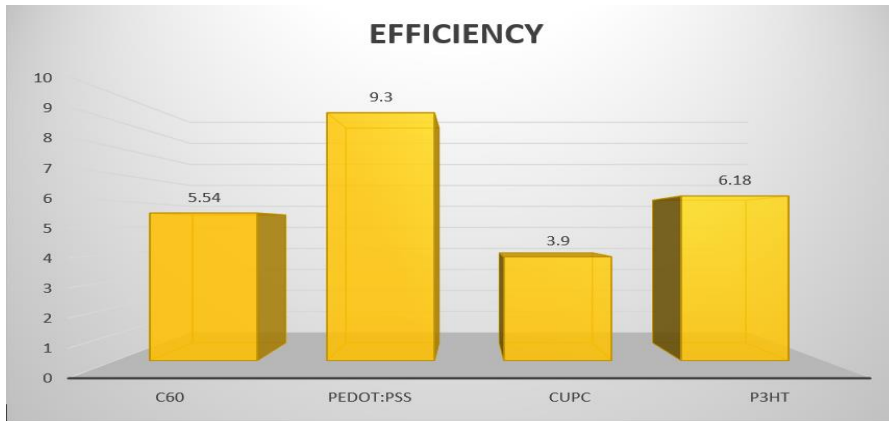
The figure 5.12 shows the Photon Distribution at different layers of the bulk-heterojunction structure. Most of the photon distribution is in the active layer region. So, this structure give higher efficiency (simulated value of 15.78%) because of maximum photon absorption.

5.4 Discussions

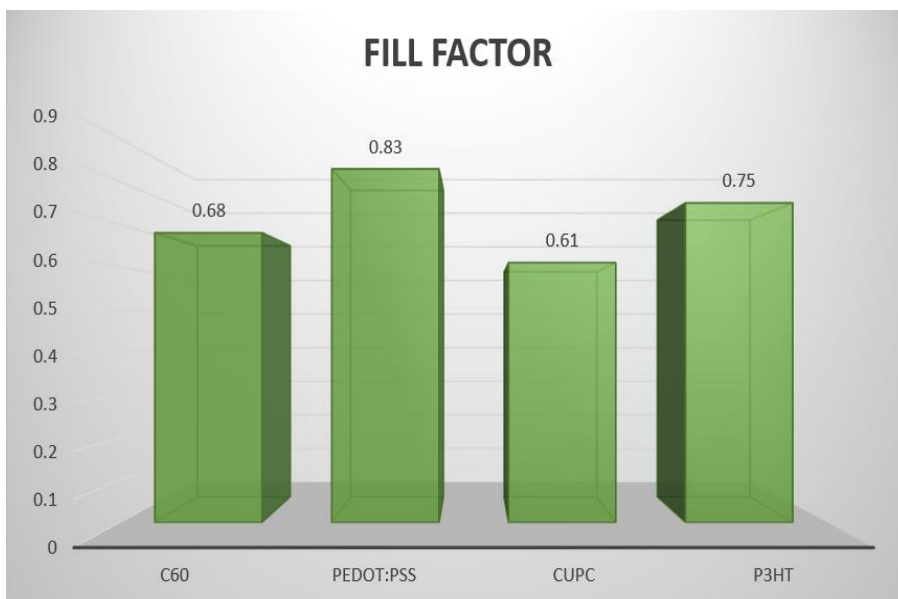
5.4.1 Single Layer Organic Solar Cell

When we reproduce information for single layer natural sun based cell, we utilized 4 different poly-mers. They are C-60 based fullerene, PEDOT: PSS, CuPC (copper phthalocyanine) and P3HT. After the reenactment done, we found that all the four materials gave most elevated efficiency in 100nm thickness. In the event that we look at their outcomes, we found that PEDOT:PSS ought to be utilized as the polymer material or natural layer to pick up the most astounding efficiency.

A similar diagram for efficiency and fill factor for mass heterojunction mix natural sunlight based cell models (dynamic layer thickness: 100nm)is demonstrated as follows. The figure 5.13a demonstrates the power change efficiency for single layer cells like C-60 Fullerene, PEDOT:PSS, CuPC and P3HT. Here the PEDOT:PSS gives the greatest efficiency of 9.30% while the CuPCgives the most reduced efficiency of 3.90%. The C-60 Ful-llerene and CuPC gives practically comparative efficiency as P3HT. The figure 5.13b demonstrates the fill factor examination for the above for single layer natural photovoltaic cell structure. Fill factor is most minimal for the greatest efficiency structure of PEDOT:PSS and the most elevated for least efficiency structure of CuPC.



(a) Efficiency Comparison for Single layer OPV



(b) Fill Factor Comparison for Single Layer OPV

Figure 5.13: Efficiency & Fill Factor Comparison for Single Layer Organic Solar Cell Models.

5.4.2 Bulk-heterojunction Organic Solar Cell

For this situation of mass heterojunction natural sun powered cell, we have reenacted information for different contact sizes. Contacts are the anodes connected on the upper and lower sides of the cells. In our outcome, we see that when contact sizes are diminished to 50nm from 100nm, efficiency increments. Truth be told, if contact size is decreased to 20nm, efficiency will be at its most noteworthy worth. In any case, this sort of Nano scale anode is particularly difficult to manufacture. That is the reason we reach thickness to be in 50nm. Here visual diagrams are appeared 50nm thickness of contacts.



(a) Efficiency Comparison for bulk-heterojunction blend OPV for 150nm thickness



(b) Fill Factor Comparison for bulk-heterojunction blend OPV for 150nm thickness

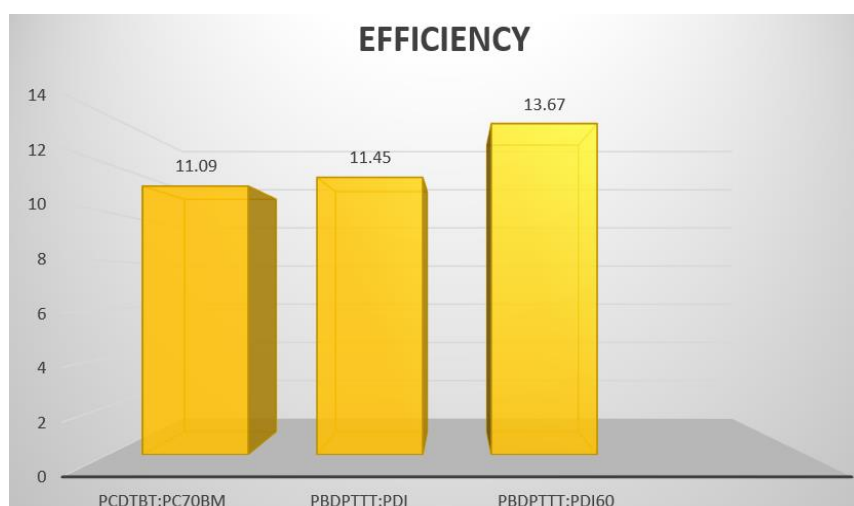
Figure 5.14: Efficiency & Fill Factor Comparison for bulk-heterojunction blend Organic Solar Cell Models for 150nm thickness

5.14a shows the power conversion efficiency for bulk heterojunction OPV cells like PCDTBT:PC70BM, PBDPTTT:PDI & PBDPTTT:PDI60. Here the power conversion efficiency is comparatively higher than single layer structures. However PBDPTTT:PDI60 theoretically gives the highest efficiency of 15.78%. The other two gives the efficiency of 14.32% and 12.09% respectively.

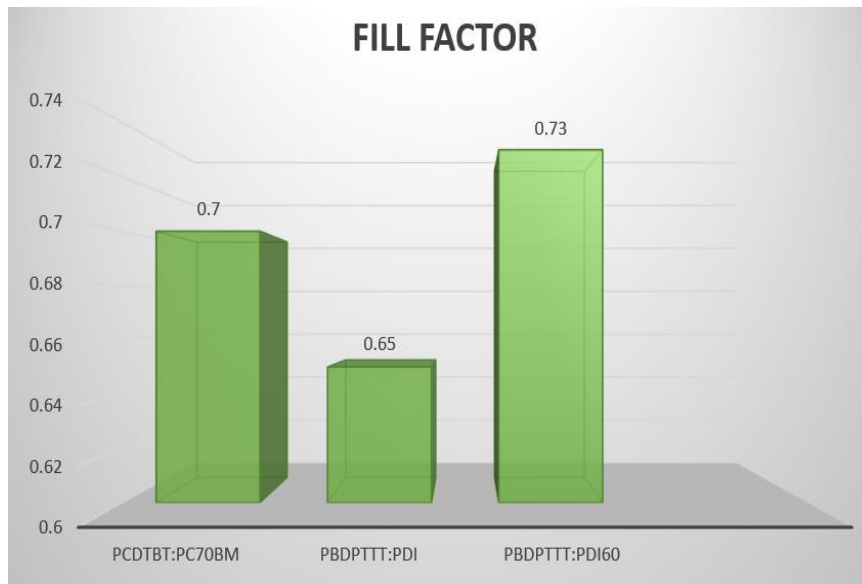
The figure 5.14b gives the fill factor comparison for PCDTBT:PC70BM, PB-DPTTT:PDI & PBDPTTT:PDI60 for 150nm of active layer thickness. As expected, the higher efficiency PBDTTT:PDI60 gives the lowest fill factor of 0.62.

For 200nm thickness of Active Layers

A comparative graph for efficiency and fill factor for bulk-heterojunction blend organic solar cell models (active layer thickness: 100nm) is shown in figure 5.15.



(a) Efficiency Comparison for bulk-heterojunction blend OPV for 100nm thickness



(b) Fill Factor Comparison for bulk-heterojunction blend OPV for 100nm thickness

Figure 5.15: Efficiency & Fill Factor Comparison for bulk-heterojunction blend Organic Solar Cell Models for 200nm thickness

Here the subfigure 5.15a gives a comparative display of efficiency for the three structures with active layer thickness of 100nm. Here the PBDTTT:PDI structure has the most efficiency among the three structures.

In 5.15b shows the fill factor comparisons for above three structures. Here also the highest efficiency structure of PBDTTT:PDI gives lowest fill factor of 0.65 and the lowest efficiency structure of PBDTTT:PDI60 gives the highest fill factor of 0.73.

Chapter 6

Conclusions and Recommendations for Future Works

A bulk heterojunction natural photovoltaic cell with an efficiency of 15.78% has been planned. Physically executed natural sun based cells give an efficiency running from 10% to 13%. Along these lines, this structure gets a progressive perspective planning natural sunlight based cell. Be that as it may, just a couple of structures with different thickness of layers and different materials have been mimicked. This product was useful in comprehending different significant parameters like greatest power, open-circuit voltage, cut off, fill factor and so forth so if in future this structure can be executed physically, the reenacted details can be coordinated with the yields from equipment usage. The hardest part in physical usage is the nano-scale design of sun oriented cells. In this way, propelled nanotechnology is required to actualize the entire structure and estimation process. Indeed, even the material PBDTTT:PDI60 is in all respects expensive and must be imported from abroad. In the event that such trend setting innovation can be actualized to plan natural sun oriented cells in our nation, it will ideally be a progressive innovation for entire world both financially and in fact, since natural cells are shabby to structure and execute contrasted with inorganic sunlight based cells.

To summarize, two sorts of structures: single layer structure and mass hetero-intersection structure have been planned. Single layer is less expensive than mass heterojunction mixed natural sun oriented cell yet the efficiency is very low. Then again, mass or mix material PBDTTT:PDI60 gives an efficiency of 15.78%, which may be the most astounding reenacted structure, yet it needs physical execution and appropriate testing in reasonable conditions to affirm.

REFERENCE

- [1] M. C. Scharber. and N. Sariciftci, "Efficiency of bulk-heterojunction organic solar cells," Progress in Polymer Science, vol. 38, 2013.

[2] A. M. Bagher, "Comparison of organic solar cells and inorganic solar cells." *International Journal of Renewable and Sustainable Energy*, vol. 3, pp. 53–58, 2014.

[3] <https://www.ukessays.com/essays/physics/organic-solar-cells-history-principles8498.php>

[4] http://www.columbia.edu/~jcc2161/documents/Solar_Energy.pdf

[5] <https://www.hindawi.com/journals/ijp/2010/123534>

[6] A. Hicks, "Organic photovoltaics research," Office of Energy Efficiency & Renewable Energy, Tech. Rep. [Online]. Available: <https://www.energy.gov/eere/sunshot/organic-photovoltaics-research>.

[7] S. Sze and K. Kwok, *Physics of Semiconductor Devices*, 3rd ed. John Wiley & Sons, Inc, 2009.

[8] M. Thekaekara, "Data on incident solar energy," *Suppl. Proc. 20th Annu. Meet. Inst. Environ.*, p. 21, 1974.

[9] H. C.H., "Limiting efficiency of ideal single and multiple energy gap terrestrial solar cells," *Journal of Applied Physics*, vol. 51, p. 4494, 1980.

[10] Nelson and Jenny, "Polymer: Fullerene bulk-heterojunction solar cells," *Materials Today*, vol. 14, pp. 462–470, 2011.

[11] "Organic solar cells - fundamental insight paves the way to commercialization," p. 1, 2013. [Online]. Available: <http://www2.imec.be/content/user/File/ic33/Organic%20solar%20cells.pdf>

[12] R. P. N., "Leading edge research in solar energy," Nova Science Publishers, 2007.

- [13] D. Davis, "Organic photovoltaic cells," pp. 41–42, 2005. [Online]. Available: http://www.chemistry.illinois.edu/research/organic/seminar_extracts/2005_2006/davis_douglas.pdf
- [14] Hoppe, H. . Sariciftci, and N. S., "Organic solar cells: An overview," *J. Mater*, vol. 19(7), pp. 19 242–1945, 2004.
- [15] M. D.G. and T. M.A., "Solar cells: Pictures from the blended zone," *Nature Materials*, vol. 5(9), pp. 675–676, 2006.
- [16] H. J.J..M and F. R.H., "Clean opinion in solid state and material science," Imperial College Press, pp. 377–445, 2001.
- [17] K. S., "Electrical and optical characterization of poly light emitting diodes," *Synthetic Metals*, vol. 54, pp. 427–433, 1993.
- [18] S. Aldrich, "Organic photovoltaics," In Website. [Online]. Available:<http://www.sigmaaldrich.com/materials-science/organic-electronics/opv-tutorial.html>
- [19] Cao, Weiran, Xue, and Jiangeng, "Recent progress in organic photovoltaics: device architecture and optical design," *Energy & Environmental Science*, vol. 7, p. 2123, 2014.
- [20] F. Yang, "Controlled growth of a molecular bulk heterojunction photovoltaic cell," *Nature Materials*, vol. 4, pp. 37–41, 2005.
- [21] F. Glöcklhofer, D. Lumpi, M. Kohlstädt, O. Yurchenko, U. Würfel, and J. Fröhlich, "Towards continuous junction (CJ) organic electronic devices: Fast and clean post-polymerization modification by oxidation using dimethyldioxirane (DMDO)," *Reactive and Functional Polymers*, vol. 86, pp. 16–26, jan 2015.
- [22] Y. Park, J. Berger, P.-A. Will, M. Soldera, B. Glatz, L. Müller-Meskamp, K. Taretto, A. Fery, A. F. Lasagni, K. Vandewal, and K. Leo, "Light trapping for flexible organic photovoltaics," sep 2016.
- [23] J. LI and A. C. Grimsdale, "Carbazole-based polymers for organic photovoltaic devices," *Chemical Society*, 2010.

- [24] K.-C. Li, J.-H. Huang, and et al, "Tunable novel cyclopentadithiophene-based copolymers containing various numbers of bithiazole and thienyl units for organic photovoltaic cell applications," *Macromolecules*, vol. 42, no. 11, pp. 3681–3693, jun 2009.
- [25] C.-E. Cheng, F. Dinelli, and C.-T. Yu, "Influences of thermal annealing on p3ht/pcbm interfacial properties and charge dynamics in polymer solar cells," *Japanese Journal of Applied Physics*, vol. 54, 2015.
- [26] A. K. K. Kyaw, D. H. Wang, D. Wynands, J. Zhang, T.-Q. Nguyen, G. C. Bazan, and A. J. Heeger, "Improved light harvesting and improved efficiency by insertion of an optical spacer (ZnO) in solution-processed small-molecule solar cells," *Nano Letters*, vol. 13, no. 8, pp. 3796–3801, aug 2013.
- [27] Kim and Y. Hyun, "Highly conductive pedot:pss electrode with optimized solvent and thermal post-treatment for ito-free organic solar cells," *Advanced Functional Materials*, vol. 21, pp. 1076–1081, 2011
- [28] J. Yang and W. Chen, "Organic electronics," *Organic tandem solar cell using active inter-connecting layers*, vol. 13, 2012.
- [29] Y. Gao, R. Mackenzie, and Y. Liu, "Engineering ultra long charge carrier lifetimes in organic lifetimes in organic electronic devices at room temperature," *Advanced Materials Interfaces*, vol. 2, 2015.
- [30] H. Kim, C. M. Gilmore, A. Piqu, J. S. Horwitz, H. Mattoussi, H. Murata, Z. H. Kafafi, and D. B. Chrisey, "Electrical, optical, and structural properties of indium–tin–oxide thin films for organic light-emitting devices," *Journal of Applied Physics*, vol. 86, no. 11, pp. 6451–6461, dec 1999.
- [31] X. Guo, X. Liu, F. Lin, H. Li, Y. Fan, and N. Zhang, "Highly conductive transparent organic electrodes with multilayer structures for rigid and flexible optoelectronics," *Scientific Reports*, vol. 5, p. 10569, may 2015.
- [32] Sergeant and N. et al., "Design of transparent anodes for resonant cavity enhanced light harvesting in organic solar cells," *Advanced Materials*, vol. 24, pp. 728–732, 2012.

