Numerical Simulation and Performance Optimization of Organic Solar Cell with Improved Efficiency

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CERTIFICATE OF RESEARCH

This is to certify that the work presented in this particular thesis paper is the outcome of research completed by the candidate under the supervision of Prof. Dr. Md. Ruhul Amin, Professor, Electrical and Electronic Engineering (EEE). It is also declared that neither this thesis work nor any part thereof has been submitted anywhere else for the reward of any degree or any judgment.

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Table of Contents

List of Tables

List of Figures

List of acronyms

AM1.5	AIR MASS 1.5
Al	Aluminum
ETL	Electron transport layer
EQE	External quantum efficiency
FF	Fill Factor
GPVDM	General-Purpose Photovoltaic Device Model
GUI	Graphical user interface
HTL	Hole transport layer
ITO	Indium tin oxide
IJP	Inkjet printing
VOC	Open circuit voltage
OPV	Organic photovoltaic
PET	Polyethylene Terephthalate
PCE	Power Conversion Efficiency
R2R	reel to reel
Se	Selenium
ISC	Short Circuit Current
STC	Standard Test Conditions

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Abstract

Organic solar cells (OSCs) are considered one of the most important upcoming photovoltaic technologies. Enhancing the overlap between absorption spectra of OSCs and solar spectrum is one way to boost their performance. In this work an organic solar cell is introduced and characterized which uses P3HT:PCBM**(**Donor-poly(3-hexylthiophene-2,5-diyl): Accepter-[6,6]PhenylC61butyricacidmethylester)andPTB7:PC70BM(DonorPoly[[4,8bis[(2ethylhexyl) oxy]benzo[1,2b:4,5b']dithiophene2,6diyl][3fluoro2[(2ethylhexyl)carbonyl]Thieno[3,4b]thiop henediyl]]:Accepter-[6,6]-Phenyl-C70-butyric acid methyl ester) as photoactive absorbing layer respectively. Throughout the work, a 3D software simulation called GPVDM is used to model J-V characteristics for various designs. Tandem organic solar structures were implemented to increase performance even further. An illumination level of 1000 W/m^2 (AM1.5G standard) and a concentration level of 1 Sun is considered for all the simulation in the work. The top and bottom subcells' active layer thicknesses were varied to optimize the design. Using different materials for the HTL , ETL , and intermediate layer strengthened our structure even further the change in efficiency was plotted against a single increasing parameter, with all other parameters held constant. After analyzing those curves, we reached the optimum thickness for top front sub cell 330nm and lower bottom sub cell 55nm and the final design is proposed which yields power conversion efficiency 11.11% .We also discussed about the potential improvisations of our design that we are optimistic about.

Chapter 1

Introduction

With the globe population steadily increasing, energy demand is projected to rise up to 40% by 2035. As the world's demand for electrical energy rises, it's more necessary than ever to generate energy from sustainable and unconventional sources. The fossil fuel supply is finite and will inevitably run out. The challenge is to search out an alternative that would be beneficial in the sense of solving the energy crisis and during this regard, solar energy can play an emergent role [1]. Despite the fact that financially solar cells are more costly, anyway production and establishment cost will be brought down soon. Truth be told, a new report from the International Energy Agency expresses that photovoltaics and solar thermal systems could produce 27% percent of electrical energy by 2050, which would make solar energy the single biggest source of electricity by mid-century.

1.1 Solar Energy

Solar energy is from the sun that comes due to internal fusion of Hydrogen atoms into Helium atoms. It is estimated that solar energy will be one of the promising means through which electricity will be harnessed as well as contribute substantially to energy used in the transportation infrastructure.

The pros and cons of solar cells are enumerated below:

Table 1-1: Pros and cons of solar cells [2]

Pros	**Cons**
Source of fuel is gigantic and unlimited	Diffusive fuel source (sunlight is low density energy compared to other fuel source)
There will be no waste, burning, or dumping of nuclear material	High installation expenses
Small operation cost	Poor reliability of auxiliary elements including storage
Operation under normal room temperature (no involvement of high temperature corrosion or any kind of safety issues)	Commercially not that much availability of system installation at present
Flexible and quick installation	Less economically friendly compared to other fuel source
Public approval is very huge.	
First rate safety record	

1.2 Solar Cells

1.2.1 Background

Solar cells are semiconductor gadgets that work using photon absorption to turn incident light into electricity, resulting in the creation of electron-hole pairs. This procedure of electricity generation from light absorption, which is acknowledged as the photovoltaic effect, was initially discovered in 1839 by the French physicist A.E, Becquerel [3]. The very first solid-state photovoltaic device was fabricated many years afterwards, by Charles Fritts, in 1883.He laminated Se with a very intensely thin layer of gold to compose the junction. The photovoltaic device was under 1% efficient [4]. At Bell Laboratories the first practically feasible photovoltaic cell was constructed during 1954 [5] by the three scientist- Daryl Chapin, Calvin Souther Fuller and Gerald Pearson. They utilized a diffused Silicon p-n junction which accomplished 6% efficiency.

At present, solar cell are composed with many diverse technologies and the efficiency range that these devices can accomplished quite impressive. In today's world, we have bulk Si solar cells, thin film solar cell fabricated from Si or CdTe, dye-sensitized solar cells, organic solar cell and so on. In the present time solar cells are used for mass generation of electricity.

1.2.2 Types of Solar cells

The three primary types of solar cells currently being commercialized are monocrystalline, polycrystalline (also referred as multi-crystalline), and thin-film [6]. Each type has its own set of benefits and drawbacks, and the best solar panel type for one's installation will be decided by factors specific to one's home and desired device characteristics [6].

Monocrystalline cells [7]

Single crystalline silicon is used to make monocrystalline solar cells. They have a distinct appearance since the cells are often colored and have a cylindrical shape. designers carved out the all sides of monocrystalline cells to keep costs down and efficiency at optimum levels which is the result of their distinctive look.

Polycrystalline Solar Cells [7]

In 1981, polycrystalline solar cells were first made available to the general public. Polycrystalline cells, unlike monocrystalline cells, do not require cutting all four sides. Silicon is liquified and poured into square forms instead.

Thin-film solar cells [6]

Dissimilar to monocrystalline and polycrystalline solar cells, thin film cells are produced utilizing a diverse of substrates. The most pervasive sort of thin film is built using CdTe. Producers use a layer which is made of CdTe in between transparent layers which help capturing sunlight. This form of thin-film applications often has a protective glass coating on the top.

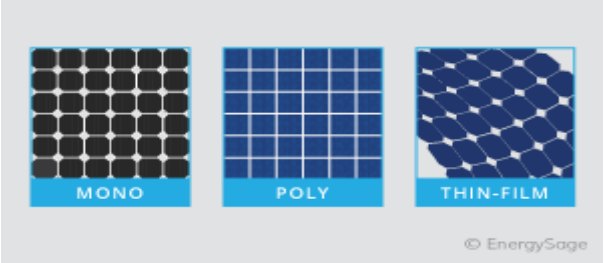


Figure 1-1:Different types of solar panels [8]

Most of the decision on the desired type of solar panel will be focused on the details of customer's property and situation. Monocrystalline, polycrystalline, and thin-film panels each have their own collection of benefits and drawbacks, and the best choice depends on user's property and solar project goals.

Table 1-2: Benefits and Drawbacks of different types of solar cells [6]

Type of Solar cell	Benefits	Drawbacks
Monocrystalline	High effectiveness/execution with aesthetics	Greater expenses
Polycrystalline	Cost-effective	Comparatively Lower efficiency/performance
Thin-film	Versatile and adaptable Lightweight	Lowest level of productivity and results

1.3 Organic Solar Cells

Inorganic solar cells, like typical silicon solar cells and multijunction solar cells, are comparatively developed technologies, with power efficiencies accomplishing record range of about 24.7% for crystalline silicon solar cells (Zhao et al. 2001) and above 42.3% for few multijunction solar cells exposed to more than 400 suns [9]. But fabrication techniques involve in a lot of complex measures which makes solar cells expensive and uncompetitive compared to other conventional energy sources for example coal, natural gas etc. So, researchers are exploring for alternative techniques and materials for solar energy generation to overcome these drawbacks. Organic solar cells are one of the lucrative fields in this regard.

An OPV cell is comprised of an absorbing layer which consists of organic semiconductors – usually polymers or small molecules. A high degree of synthesis (alternating single as well as double bonds) is necessary for organic substrates to be conducting or we can say semiconducting. When an organic molecule is conjugated, the electrons associated with the double bonds become nonexistent. These electrons are similar to valence electrons in inorganic semiconductor materials and have comparatively higher energies than others in the molecule [10]. Light absorption in organic solar cells results in production of excitons in molecular materials, instead of free electrons and holes, which is an elementary difference between traditional IPV cells and OPVs. A strongly coulombically bound electron hole pair can be thought of as an exciton. It can be called a mobile excited state because of its electrical neutrality and the strong binding energy between the hole and the electron. Because of this fundamental distinction, the processes involved in converting photons to electrical energy vary from those in IPV cells.

1.4 Software

GPVDM (General-purpose Photovoltaic Device Model)

All the simulations conducted for this work were done by GPVDM. Gpvdm is a 1D/2D opto-electronic gadget model that can be utilized to recreate solar cells, LEDs, diodes, FETs, and other opto-electronic gadgets. It Solves the drift diffusion equations using the finite difference method, the optical equations using ray tracing or the transfer matrix method [11]. Gpvdm can do many different things like reenact PL/EL spectra, IS, IMPS, import FDTD information and so forth. The model can yield Current voltage bends, the transient reactions (current/voltage) to laser beats and the reaction of the gadget to the use of a sinusoidal optical or electrical bother [13]. The model is partitioned into two sections, the GUI and the back-end solver where the job of the GUI, is basically to alter the info records (sim. gpvdm) and see the outcomes. It is the back-end solver which does all the calculations [13].

Users can provide values for necessary parameters (band gap, layer thickness, mobility, and so on) as inputs to this software, or they can use built-in parameters. This program can simulate devices made of any material for which these parameters are defined.

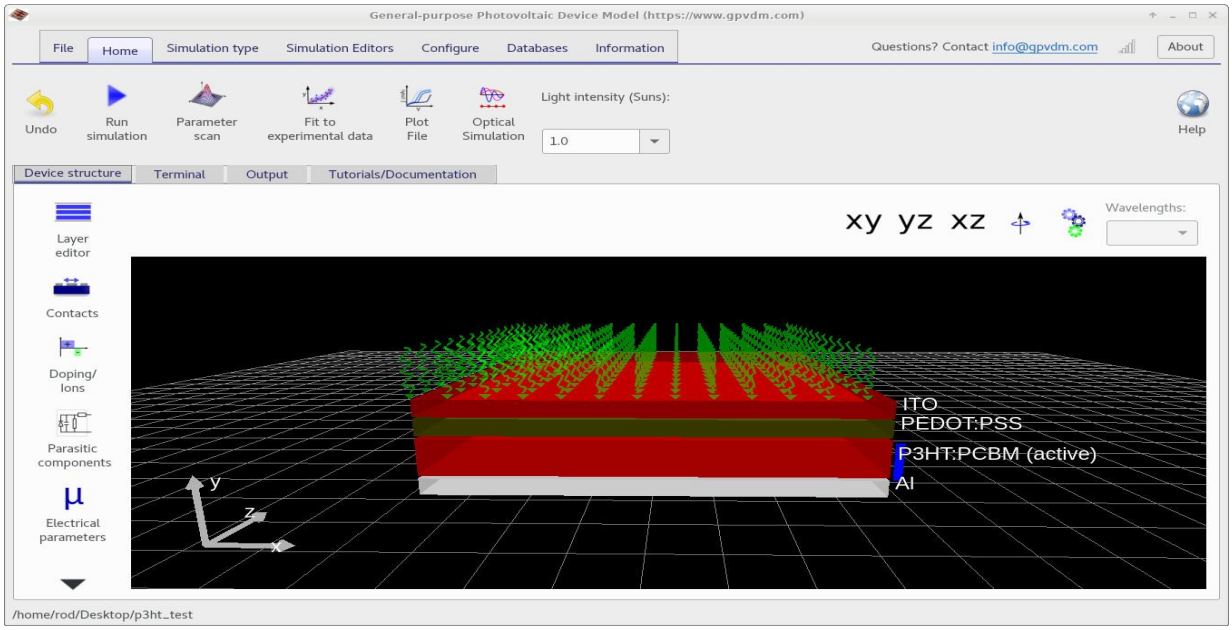


Figure 1-2:A general structure of GPVDM software simulation of typical OPV [12]

1.5 Research Outline

In our work, at first, we have introduced, characterized and optimized an organic solar cell using GPVDM simulator. Here **P3HT:PCBM(**Donor-poly(3-hexylthiophene-2,5-diyl): Accepter- [6,6]-Phenyl-C61-butyric acid methyl ester) and **PTB7:PC70BM**(Donor-Poly[[4,8-bis[(2ethylhexyl)oxy]benzo[1,2b:4,5b']dithiophene2,6diyl][3fluoro2[(2ethylhexyl)carbonyl] Thieno[3,4-b]thiophenediyl]]:Accepter-[6,6]-Phenyl-C70-butyric acid methyl ester) functions as the active layer(absorber) of the cell.

However, due to low efficiency (5.59%), we modified our built structure to a tandem OPV. For higher quality, the thickness of active layers, as well as various materials such as HTL, ETL and interlayer, were varied. The final design yields 11.1 percent, which is a good result given that OPVs are less effective than polycrystalline or thin film PVs.

Chapter 2

Organic Solar Cell

Organic photovoltaic are especially encouraging choices for solar cell energy generation in view of the wealth of their constituent components and base materials, their minimal effort, and relative simplicity of synthetic combination; in addition, monstrous manufacture of related materials has been applied and comprises a set up and hearty innovation. In less than a decade, organic solar cells have progressed from low-efficiency laboratory-based devices to the first consumer devices . While other types of organic solar cells are starting to compete, bulk heterojunction solar cells made from conjugated polymers and fullerene acceptors have still accomplished the highest efficiencies.

2.1 Device Structure[13]

The device design of organic photovoltaic cells is not the same as traditional inorganic photovoltaic cells. Sandwich geometry is used to fabricate most device architectures. In addition to the transparent substrate, an organic photovoltaic system consists of at least four layers, as shown in Figure 2.1. Glass, polyester, or a variety of other transparent materials may be used as the framework from which the device will be illuminated. Organic semiconductor materials make up the active layer surface , which includes conjugated polymers as electron donors and fullerene derivatives as electron acceptors.

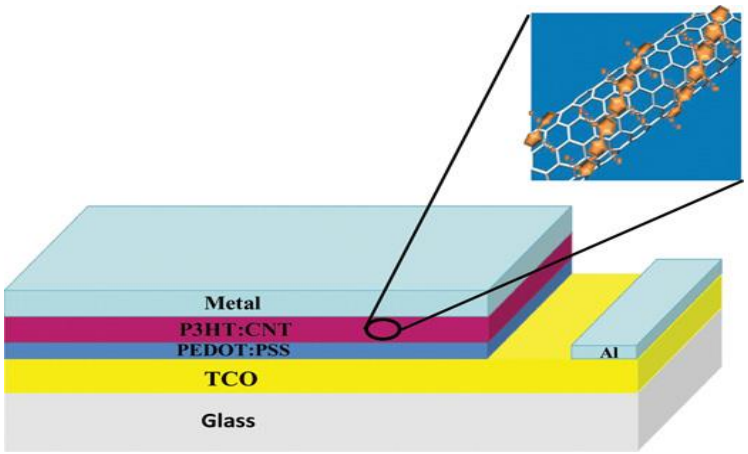


Figure 2-1: A basic organic solar cell. [15]

This active layer is deposited on a substrate sandwiched between two electrodes. Light passes through the transparent layer, which can be flexible, in this structure. Glass or polyethylene terephthalate are the most commonly used substrates (PET). The anode is made up of a semi-transparent oxide layer, typically ITO that works as an electrode, helping photons to pass through and collecting holes . A HTL of the conductive polymer poly (3 4-ethylenedioxy-thiophene)- poly(styrene sulfonate) (PEDOT:PSS) is spin coated on the ITO surface, preventing electrons from touching the anode and the anode substrates from diffusing into the photoactive layer. Through vacuum evaporation and solution processing methods, the photoactive layer is comprised of a typical solution containing the electron donor and the electron acceptor immersed in a suitable solvent. Aluminum is the most common cathode used to absorb electrons from the chip, but silver or calcium may also be used. LiF has been recommended as a shielding buffer layer between the cathode and the active layer to prohibit cathode elements from diffusing to the active layer while also acting as an electron-transporting and hole-blocking layer (Jing et al. 2005). The key disadvantage of utilizing any of these buffer layers is the high deposition temperature, which can cause significant harm to the active layer underneath.

2.2 Operating Principle[14]

Organic solar cells' working mechanisms are one of the tops studied as well as discussed topics. Generally, all of the main distinctions in mechanism in organic solar cells emerge from the production of electrostatically bound electron-hole pairs rather than free charges in organic solar devices. This definition is also thoroughly clarified.

2.2.1 Photon Absorption and Generation of Excitons

Organic molecules with a conjugated pi electron framework have a broad variety of electrical and optical properties. The bandgap in organic semiconductors is calibrated to the energy of the spectrum of the sun , allowing photon absorption and the formation of excitons, which are electrostatically bound pairs of electron-hole. Rather than excitons, inorganic silicon semiconductors emit free charges. All the variations in production of electricity mechanisms in inorganic and organic solar systems are driven by this significant change.

2.2.2 Diffusion of Excitons

Excitons produced by photons have a very limited lifespan of a few picoseconds, restricting their mobility to some polymer units or molecules. To reduce the extra fragile energy, the exciton travels inside the chain, causing chain elongation, which is collectively known as polaron. However, intermolecular exciton transitions do occur, which is referred to as the hopping mechanism. The average mobility of excitons is restricted to a 10 nm range, which is referred to as the exciton diffusion duration. Diffusion of excitons duration is necessary in the construction and quality of the device since excitons must dissociate within this range.

2.2.3 Dissociation of Excitons

The method of breaking the electrostatically bound pair of electron and hole into free charges is called exciton dissociation. The donor acceptor interfaces or junctions are where excitons dissociate. The donor and acceptor materials are constructed in such a way that materials' LUMO level vary, causing exciton dissociation. The divergence in LUMO energy levels of the donor and acceptor must be greater than the exciton binding energy for effective separation. The divergence is usually about 0.2-0.3 eV.

Generally, ($LUMO_D$-$LUMO_A$)>Exciton binding energy is implemented to ensure effective charge separation.

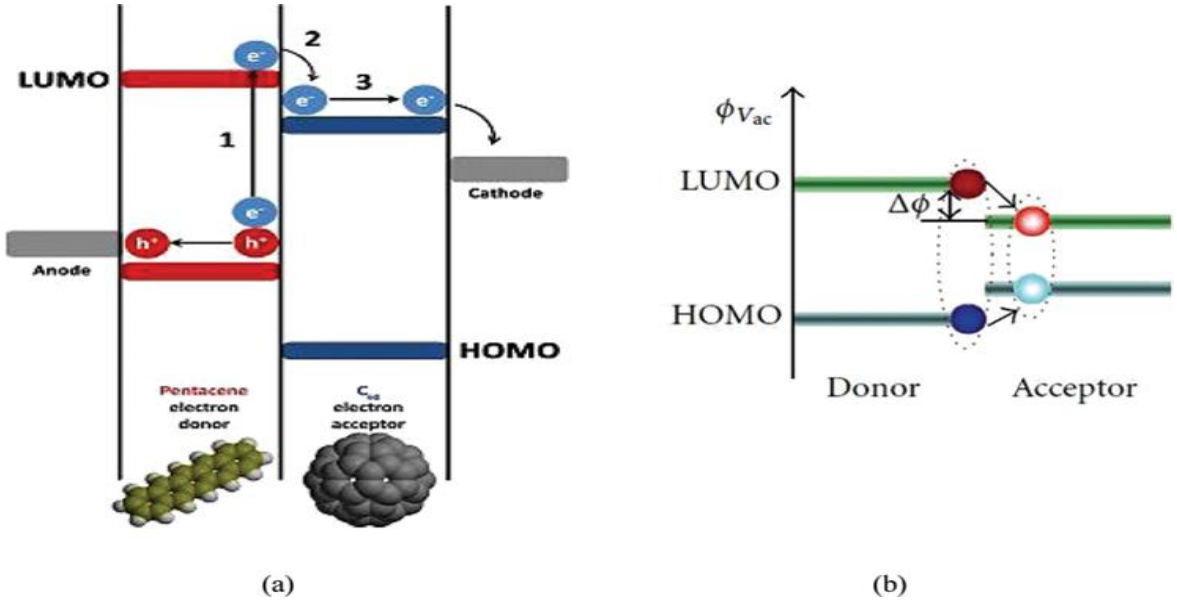


Figure 2-2**:** a) Exciton separates selectively in a staggered gap.), b) The entire exciton is moved from donor to acceptor without dissociation in a nonreferential straddling distance. [15]

2.2.4 Transportation of Free Charge Carriers

The free charges pass through the system once they've been generated .Materials to be processed at the electrodes the beginning .They're wired into the external circuit . The charge transport efficiency is calculated by organic impedance and electrical conductivity

2.3 Solar Cells and Their Characteristics[13]

VOC, ISC, FF, and power conversion efficiency are the most critical factors that are commonly used to calculate the output of solar cells (PCE). The most important metric for evaluating photovoltaic cell output is PCE. It is defined as follows:

$$P_{max} = V_{OC} I_{SC} FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Where:

$\mathbf{V_{oc}}$ is the open-circuit voltage;

$\mathbf{I_{sc}}$ is the short-circuit current;

FF is the fill factor and

η is the efficiency.

Photovoltaic cell power conversion efficiencies are calculated under international STC, which include a temperature of 25 °C, a 1000 W/m2 irradiance, and an AM1.5.Consequently, the power conversion efficiency of a system is determined by three main device characteristics. Figure 2.3 depicts a J-V curve.

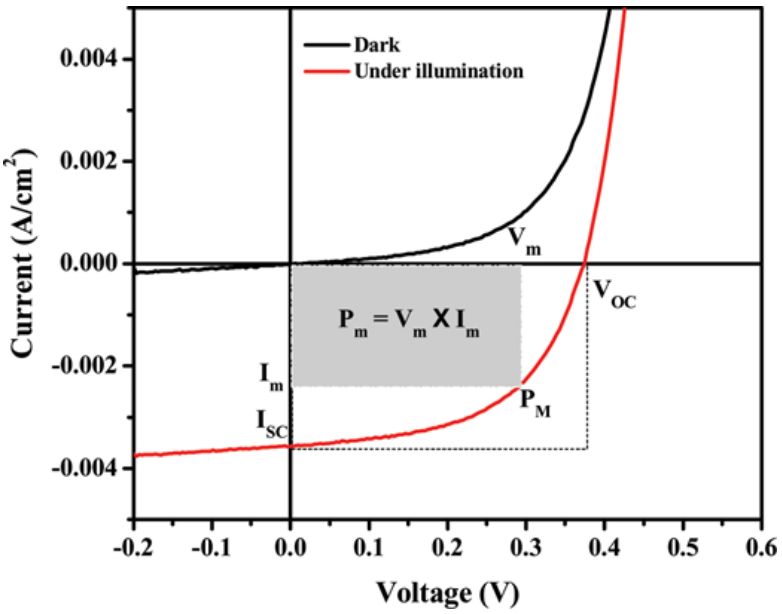


Figure 2-3: A basic current-voltage characteristic curve of a solar cell.[15]

2.3.1 Open circuit voltage

The difference in potential between two terminals of solar device when no current is flowing through it is known as open circuit voltage (V_{oc}). The divergence in energy between the donor's HOMO level and the acceptor's LUMO level [17]as shown in Fig. 2 is calculated to be the highest value of Voc. Scharber et al. [18] explored the correlation between D-A interface energy levels and open circuit voltage for 26 separate bulk heterojunction solar cells in 2006. The acceptor substance for each device was PCBM, which is one of the most appropriate fullerene compounds, while the donor substance was distinct for each device. A simple relationship in between HOMO of the substrate and the V_{oc} of the system has been extracted from this study [18], where q is the fundamental charge:

$$\mathbf{Voc} = \frac{1}{q}\left(\mathbf{I}\, E_{homo}^{Donor} \mathbf{I}^{-}\, \mathbf{I}\, E_{lumo}^{Donor}\, \mathbf{I}\right) - \mathbf{0.3\ V}$$

However, rather than theoretical interpretation, these findings are founded on empirical research. Several reports on the origin of V_{oc} have refuted this relationship [19], indicating that, unlike silicon solar cells, the origin of V_{oc} in bulk heterojunction organic solar cells is currently unknown.

2.3.2 Short Circuit Current Density

The maximum photocurrent density that can be collected from the system under short circuit conditions is known as the J_{sc}. The following equation connects it to the EQE:

$$J_{SC} = \frac{q}{\hbar C} \int_{\lambda min}^{\lambda max} EQE(\lambda) \times P_{inc}(\lambda) \times d\lambda$$

Where q is the electron charge ,ħ is the Planck constant, c is the speed of light, and ƛ is the wavelength of light. The EQE is referred as the ratio of the amount of charge carriers collected to the amount of incident light at a specific wavelength. As a result, EQE is determined by five factors:

η_{abs} : The photon absorption efficiency of the system is defined by this parameter (Fig. 2.4a). It demonstrates the most efficient method for increasing the J_{sc} of an OPV system [20]. Both the band gap and the absorption coefficient of the compound determine the absorption range of the material. Semiconducting polymers have band gaps above 2eV (620 nm), reducing the number of photons that can be absorbed to around 30%[21]. Interestingly, organic materials have a far higher absorption coefficient than silicon, allowing thin layers to be used[21]. Surprisingly, the fullerene acceptor material can absorb light, significantly increasing the device's J_{sc}.

η_{diff} :The capability of an exciton to separate to a D-A interface is defined by this particular factor (Fig. 2.4a). Until the exciton's excitation energy is lost through the use of the recombination phase, excitons in the photoactive substrate must meet the D-A interface, where exciton separation may take place. Since the duration of excitonic diffusion in conjugated polymers is so short[22], control over the D-A arrangement is essential for the effective exciton diffusion.

η_{diss} :The efficiencies of exciton dissociation are included in Fig. 2.4b. The energy offset generated at the D-A interface necessary to release electron must be greater than the excitonic binding energy in the substrate in order to successfully dissociate the exciton and produce free charge carriers. Usually, this value is in the region of 0.1-0.5 eV[23].

η_{tr}: In Figure 2.4c, the charge carrier transport efficiency throughout the system is included. Charge transport in organic materials is influenced by traps and recombination sites in the photoactive layer, and the stability of the organic materials [24].

η_{cc}: The charge collection efficiency at the electrodes is represented by this factor (Fig. 2.4d). The capacity of charge carriers (electrons and holes) to be inserted into the electrodes from the photoactive layer is measured by this factor. Actually, the amplitude of the LUMO level of the acceptor with respect to the vacuum level has to be smaller than the potential event of the electrode metal for optimal electron injection into the cathode. In order to effectively insert holes into the anode, the amplitude of the HOMO level of substrate with respect to vacuum level has to be larger than the potential event of the reflective anode. As a result, the electrode materials have to be specifically chosen. Intermediate layers such as PEDOT:PSS and ZnO can be used between the photoactive layer and the electrodes to enhance charge carrier penetration [25].

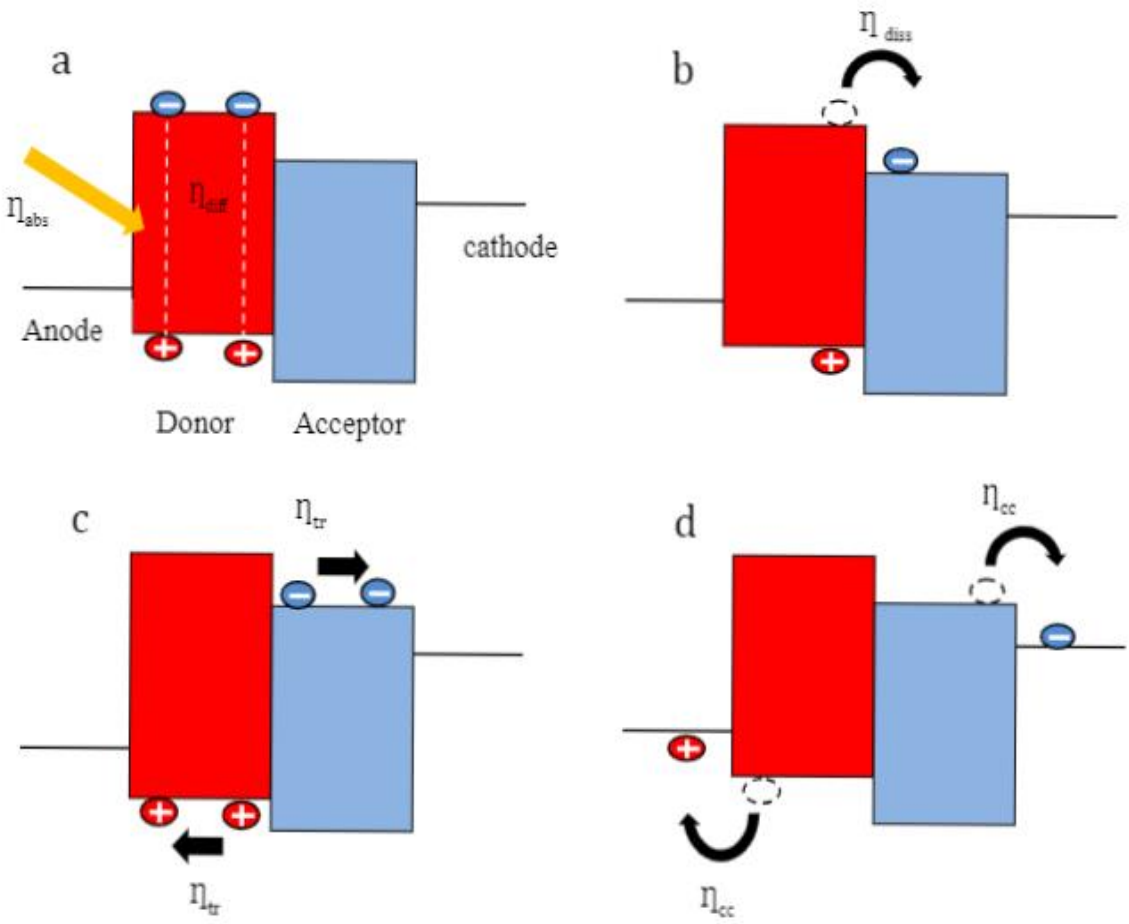


Figure 2-4: The steps of photocurrent generation: (a)absorption of photon and diffusion of exciton (b) dissociation of exciton (c) transport of charge carrier and (d) collection of charge. [13]

2.3.3 Fill Factor

The FF is a significant factor that defines the OPV device's power conversion performance. It has to do with key dimensions in the equivalent circuit: series resistance, shunt resistance, and diode[26] . The device's J-V transfer function is rectangular in the ideal case, and the maximum power provided by the cell under lighting equals the product J_{sc} and Voc. The diode's actions will diverge from the ideal scenario in practice, owing to recombination at the D-A interface and then the input power, where J_{max} and V_{max} is known as maximum power point current density and voltage, accordingly. Compared to crystalline inorganic solar cells, which have FFs of more than 80% [27,28], bulk-heterojunction organic solar cells have lower FFs due to non-ideal nanomorphology and a difference in electron and hole mobility. It was also reported that the interaction between the photoactive layer and the cathode could disturb the FF of OPVs.

2.4 Choice of Material

Organic compounds have been utilized as solar cell substrates for a long time. They have a few benefits over traditional semiconductors. However, due to narrow absorption spectra and not so impressive charge mobility, their efficiency remains low. Among these products, fullerene derivatives have a lot of potential as electron acceptors.
In our work , we have chosen two most common organic material for photoactive layer, P3HT:PCBM and PTB7:PC70BM.

2.4.1 P3HT:PCBM

Donor-poly(3-hexylthiophene-2,5-diyl)

Accepter-[6,6]-Phenyl-C61-butyric acid methyl ester

A mixture of narrow-band donor and fullerene derivate may be used to create effective organic cells, such as the P3HT:PCBM cell, which is the most efficient. A fullerene derivative is PCBM. It serves as an electron acceptor in many organic cells thanks to the high hole mobility. P3HT is a conducting polymer that belongs to the Polythiophene family . The photovoltaic effect in the blend is caused by the perturbation of the -orbit electron in P3HT[29].

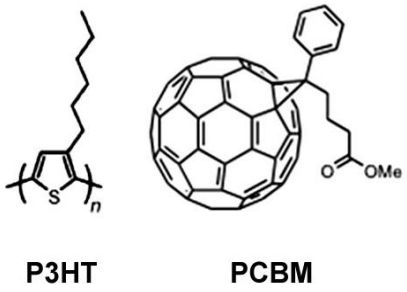


Figure 2-5: chemical structure of PH3T and PCBM [29]

As compared to semiconductors, organic polymers have a wider gap. As a result, they provide efficient absorption in the near UV region. PH3T:PCBM blends are the same way. The blend's gap is estimated 1.8eV. As shown in fig 2.6 , the largest absorption wavelength shall be about 650 nm[30].

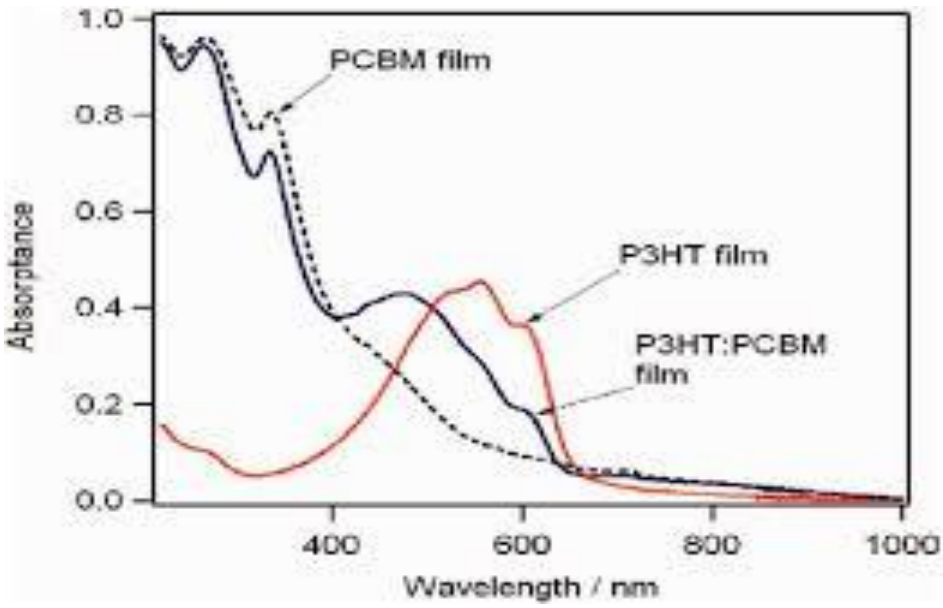


Figure 2-6: Solar absorbance spectra of P3HT , PCBM , and P3HT:PCBM [30]

The charge-generation process in the material has been studied using ultrafast techniques. The PCBM excitons are essentially split very quickly in the existence of P3HT, producing P3HT and PCBM. The charge transfer rate is higher than other potential decays of the PCBM in the excited state, implying that the excitons were extracted earlier than the electron and hole recombination. The significance of nanoscale morphology in optimizing cell efficiency

cannot be overstated. Experimental studies show that the efficiency of cells enhances when P3HT:PCBM blends follow an ordered morphology. The absorbance spectrum is found to be expanded, J_{SC} increases, and V_{OC} decreases slightly. In addition, the surface resistivity reduces.

2.4.2 PTB7:PC70BM [20]

Donor-Poly [[4,8-bis[(2-ethylhexyl)oxy]benzo[1,2-b:4,5-b']dithiophene-2,6-diyl][3-fluoro-2-[(2-ethylhexyl)carbonyl]Thieno [3,4-b]thiophenediyl]]

Accepter-[6,6]-Phenyl-C70-butyric acid methyl ester

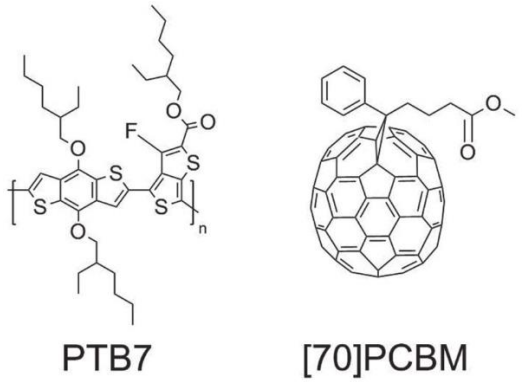


Figure 2-7: Chemical Structure of PTB7 and PC70BM [20]

Because of its prolonged absorption into the near infrared and low HOMO stage, PTB7 is one of the greatest recorded efficiencies for polymer: fullerene solar cells. PTB7 becomes a fast and convenient way to boost system efficiencies when combined with our full package of processing information. This is a cost-friendly way to enhance the efficiency and influence of devices and data for a wide range of applications.

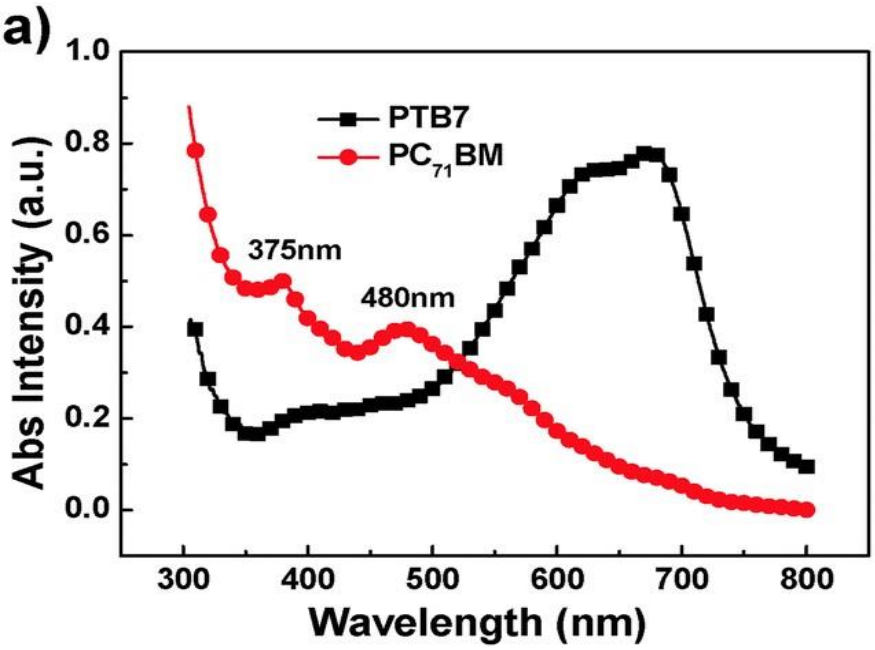


Figure 2-8: Absorbance spectrum of PTB7 film, PC70BM film[20]

PTB7 is one of the most reliable materials to utilize with because of its high solubility in a large range of solvents, making ink preparation and filtration easy . This makes it a perfect applicant for ink-jet printing, spray coating, and blade coating, among other coating techniques. PC70BM is a fullerene electron acceptor usually utilized in the most proficient organic photovoltaic gadgets. The non-balanced C70 pen of PC70BM empowers vigorous changes that are prohibited in C60, enhancing the retention attributes over PC60BM for the noticeable scope of the spectrum of the sun range [33]. This permits expanded photon collecting, as well as a conceivably larger photocurrent for gadgets utilizing PC70BM instead of PC60BM.

2.5 Initial Design

We started by designing a simple organic solar cell structure with P3HT:PCBM and PTB7:PC70BM functioning as photoactive layers, PEDOT:PSS as HTL , ITO as anode, and Al as cathode in our research. GPVDM software is used to optimize the system by adjusting the thickness of each layer.

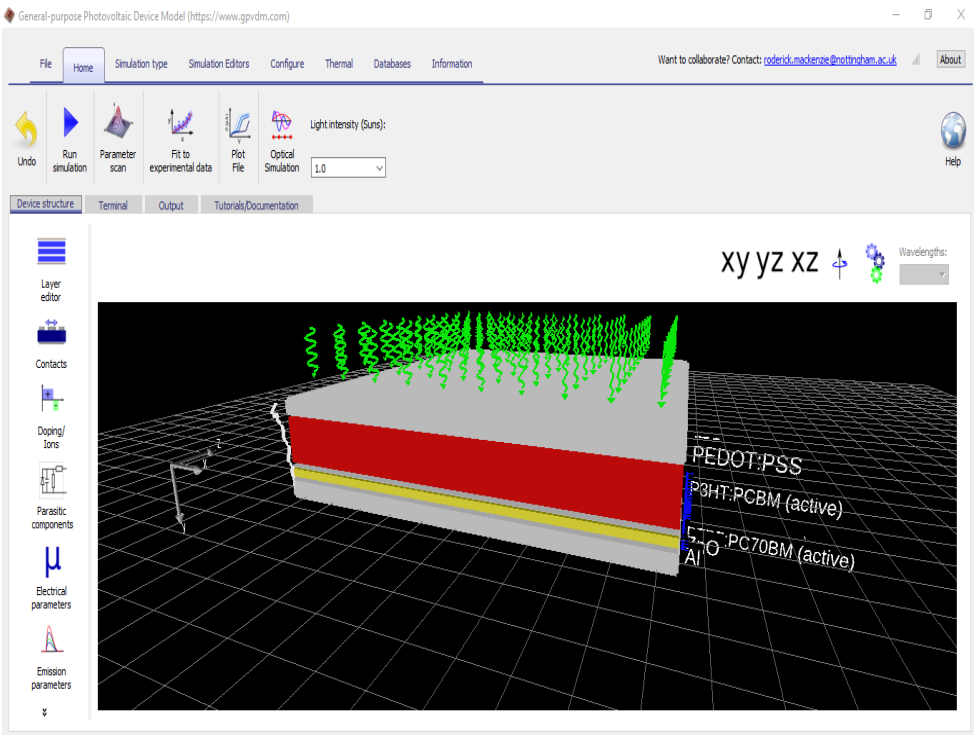
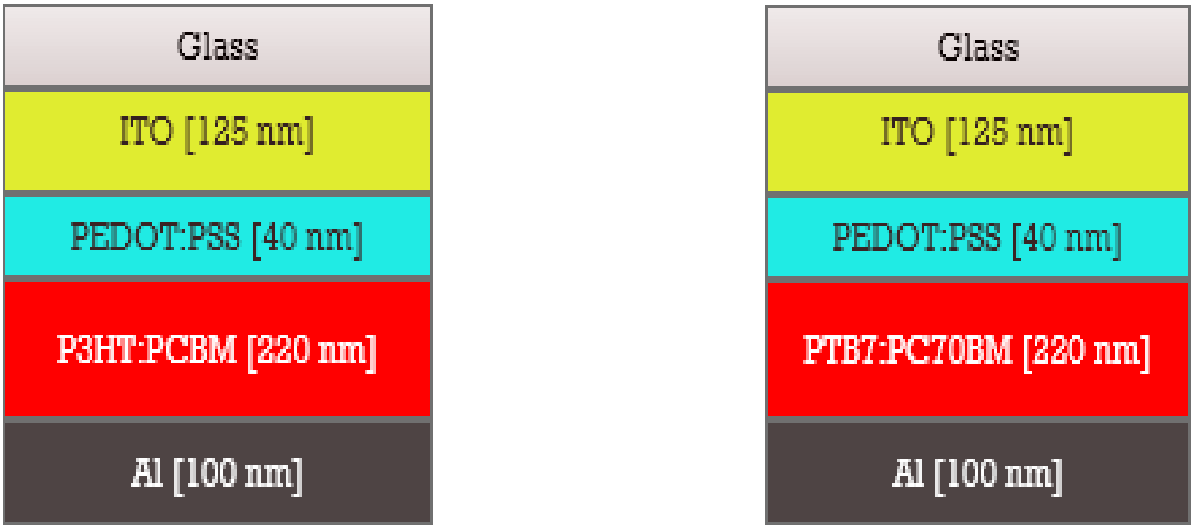


Figure 2-9: Software simulation of OPV in GPVDM



(a) (b)

Figure 2-10: (a) OSC with P3HT:PCBM active layer material ; (B) OSC with PTB7:PC70BM active layer material

2.5.1 Simulation Result

The product of optimization falls short of our expectation. We got 4.55% power conversion efficiency for the P3HT:PCBM structure and 5.59% for the PTB7:PC70BM structure (PCE). The detailed simulation result is given bellow :

Table 2-1: Software simulation result

OSC Active layer Material	Parameter			
	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	η (%)
P3HT: PCBM	0.69	9.38	69.71	4.55
PTB7:PC70BM	0.70	11.45	69.46	5.59

Chapter 3

Improvisation of Initial design

In the previous chapter, we showed our initial OPV structure, but the results were not satisfactory. To improve the efficiency of our design, we introduced Tandem Organic Solar Cell in our work.

3.1 Tandem Organic Solar Cell

In the previous 10 years, research on organic solar cells has experienced a significant advancement stage prompting significant improvements in power transformation efficiency, from 4% to 9% in single-junction device[35]. During this period, there are numerous novel technologies and applications that have been proposed and adjusted in organic solar cell device. One notable device structure that expands the solar cell effectiveness is the multi-junction tandem solar cell technology. Tandem organic solar cells are divided into two subcells with an intermediate layer between them. Adding more subcells to this form of architecture will increase the absorption spectrum, but it increases complexity in fabrication and expense. Each sub cell is designed to work in a specific part of spectrum of the sun.

3.2 Why We Prefer Tandem OPV

OPV solar cells are hindered by unreliable charge carrier extraction, quite poor carrier mobility, and a limited absorption spectrum, despite their low expense, light weight, ease of fabrication, and mechanical flexibility. Single-layer OPVs' efficiency seems to be very poor, and they don't reach the 10% efficiency requirement needed for commercial viability. This can be solved by layering two or more sub-cells with different absorption bands, with the front cell containing the material with the broader bandgap and the back cell containing the material with the narrower bandgap[36].

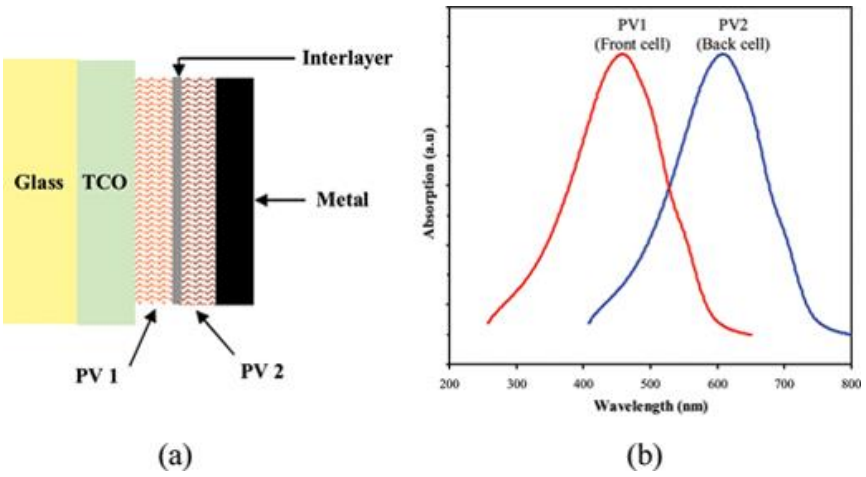


Figure 3-1: a) Basic structure of tandem organic solar cell: The shorter wavelengths are absorbed by the front PV, while the longer wavelengths are absorbed by the back PV ; b) absorption spectra of tandem solar cells.[36]

3.3 Basic Structure of a Tandem OPV Device

Tandem solar cells can be linked in series or as individual cells. Series connected cells are simpler to implement, but since the current in each cell is always the same, the optical band gap that can be used are restricted. The most common way to build tandem cells is uniformly, with all of the cells arranged in layers on the substrate and tunnel intersections connecting the individual cells.

The basic structure of a tandem organic solar cell is displayed below :

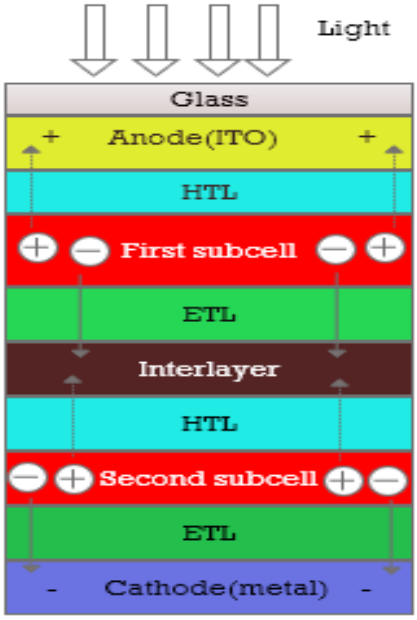


Figure 3-2: Basic Tandem Organic Solar Cell structure[39]

Depending on the structure of the interlayer and how the two electrodes are linked, there are two main types of contacts for subcells in a tandem layout: parallel or series. Tandem devices are classified into traditional and inverted systems, analogous to single junction solar cells, based on the charge collection mechanisms in their subcells, as shown in Figure 3.3

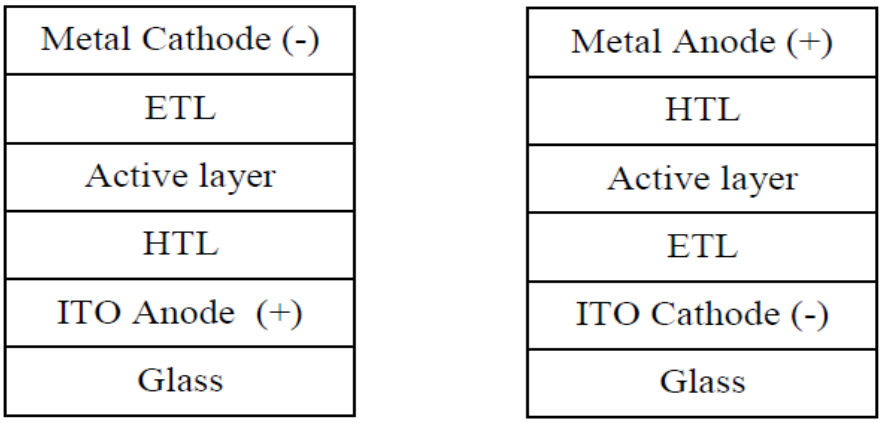


Figure 3-3:Schematic configuration of common OSC architectures: (a) Conventional architecture; (b) Inverted architecture[39]

3.4 Intermediate layer [39]

In multiple-junction solar cells, the intermediate layer is critical because it must meet a variety of mechanical, optical, and electrical requirements[37]. In a series tandem solar cell, the intermediate layer works as a recombination layer, while in a parallel tandem unit, it functions as the third electrode.

While choosing an intermediate layer the factors given below should be considered:

- It functions as a charge recombination region, associating the quasi-Fermi level of holes from one sub cell with the quasi-Fermi stage of electrons in the other (only for series tandem cells)[38]; In a nutshell, the intermediate layer must permit holes from one sub cell to recombine with electrons from another.
- It should maintain a resistance-free electrical communication between the subcells electrically.
- To mitigate absorption loss, it must be clear from an optical standpoint.

- It should be mechanically durable to safeguard the underlying layers from harm caused by the next subcells subsequent operation.

We used Ag, Au, and Al as intermediate layers in our research.

3.5 Types of Tandem Solar Cell

Multi-junction solar cell arrangements, in which two or more sub-cells with compatible absorption are layered and linked in series or parallel, provide an enticing way to overcome organic solar cells' single junction shortcomings and enhance their power conversion performance. There is diverse type of tandem organic solar cells but they mainly fit into two types.

- Homo tandem solar cell
- Hybrid tandem solar cell

The term "homo tandem organic solar cell" refers to a system in which all of the subcells photoactive layers are made of the same organic substrate. While efficiency can be enhanced by utilizing homo tandem solar cells, it is not so much because both active layers absorb photons of the same band gap.

To improve absorption spectra, hybrid tandem solar structure is introduced, where the photoactive layers of different subcells are made of different organic materials. Mostly, the top subcells have a broader band gap material than the bottom subcells, and the bottom subcells have a narrower band gap material.

3.6 Methodology

OPVs are still in the early stages of technical progress, despite their low cost, ease of fabrication, and mechanical suitability. Researchers are exploring various way to enhance efficiency , sustainability of this technology

Efficiency of OSC can be increased in following ways:

- Increasing light absorption to generate electric charge carriers
- Faster charge separation
- Charge transport to electrode with lower recombination rate

In our research, we primarily focused on increasing photon absorption spectra in order to produce more excitons . To extend the absorption spectrum shown below, we used two separate band gap materials.

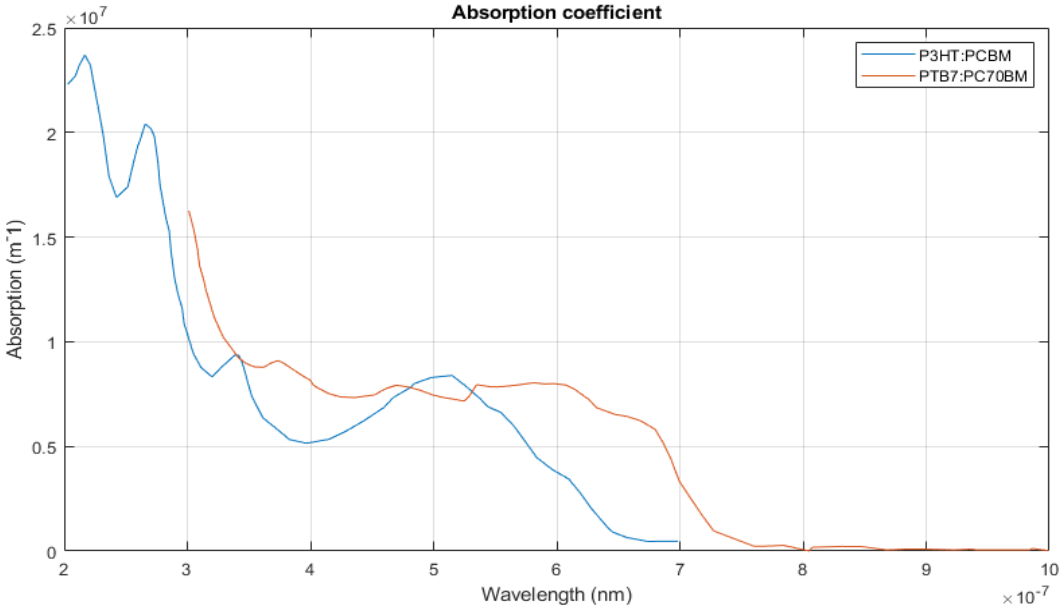


Figure 3-4: Absorption spectra of P3HT:PCBM and PTB7:PC70BM as photoactive layers of two different subcells

Chapter 4

Numerical Simulation and Optimization

This part of work represents numerical optimization of our proposed structure of tandem organic solar cell. The work is done with both homo and hybrid structure of tandem organic solar cell. Firstly, the optimization of homo structures is done with software GPVDM. Then the later portion provides the hybrid structure and our final result.

4.1 Optimization of Homo Structure

There are two proposed structures here. In first one, P3HT: PCBM organic material is utilized as both top and bottom sub-cells of active layers. And the second structure is consisted of PTB7:PC70BM material as active layers for both sub-cells.

4.1.1 P3HT: PCBM as active layer

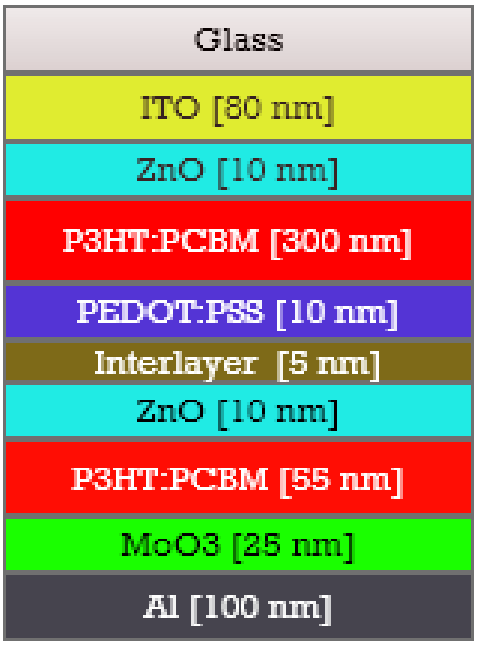


Figure 4-1 : Homo structure of P3HT: PCBM

This is our first homo structure of tandem organic solar cell. Thicknesses of each layer are optimized from our software GPVDM.

4.1.2 PTB7:PC70BM as active layer

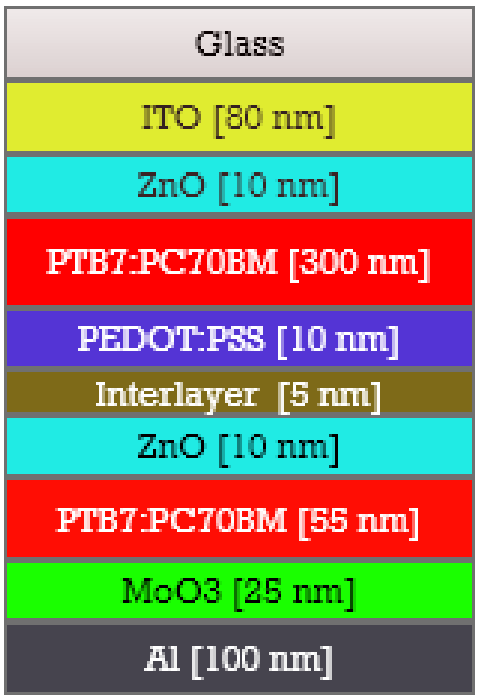


Figure 4-2: Homo structure of PTB7:PC70BM

Here is the second structure and thicknesses of each layer is optimized in same way by the software.

4.1.3 Results and Comparison between Two HOMO Structure

Table 4-1: Simulation result of two homo structures

Tandem cell Active layer Material	Parameter						
	V o c (V)	J s c (mA/cm^2)	FF (%)	Ƞ (%)	Max P (m W/ cm^2)	Voltage at max P (V)	Current at max P (mA/cm)
P3HT: PCBM Homo	1.161	12.56	73.83	10.76	10.76	0.874	12.32
PTB7:PC70BM Homo	1.47	11.83	62.35	10.91	10.91	0.994	10.96

The simulation of our optimized homo structures is done by GPVDM and found this dataset where the efficiency is greater in the later case. Other parameters are also found like open circuit voltages, short circuit current densities, FF, maximum powers, voltages at maximum power and currents at maximum power. The highest efficiency we got so far is 10.91 for homo tandem structure with PTB7:PC70BM as active layers. For increasing the efficiency furthermore, the hybrid structure is designed. The efficiency in hybrid structure is increased because there two active layer materials in it. One is for absorbing the lights with higher wavelengths (P3HT: PCBM) and another one is for the lower wavelengths (PTB7:PC70BM).

4.2 Optimization of Hybrid Structure

The proposed hybrid structure of tandem organic solar cell consists of two different type active layer materials. P3HT: PCBM material is used for top sub-cell and PTB7:PC70BM is used for bottom sub-cell.

Figure 4-3: Hybrid structure of P3HT: PCBM for top sub-cell and PTB7:PC70BM for bottom sub-cell

So, this is the preferred hybrid structure of the work. Materials of each layer such as HTL, ETL, interlayer is determined by simulating in software.

4.2.1 Optimization of HTL Material

For optimizing the HTL, three materials are selected based on their availability and cost efficiency. Those are PEDOT: PSS, MoO_3 and V_2P_5. Then those materials are simulated by GPVDM and the result with best efficiency is selected for the final structure.

Table 4-2: Simulation result of optimizing HTL material

Tandem Cell HTL Material		**Parameter**						
Top Sub cell	Bottom Sub cell	V o c (V)	J s c (mA/cm^2)	FF (%)	Ƞ (%)	Max P (m W/ cm^2)	Voltage at max P (V)	Current at max P(mA/cm^2)
PEDOT: PSS	**PEDOT: PSS**	**1.42**	**12.18**	**64.06**	**11.1**	**11.1**	**0.99**	**11.17**
MoO_3	MoO_3	1.41	11.86	64.38	10.81	10.81	0.994	10.87
V_2O_5	V_2O_5	1.31	7.65	68.87	6.94	6.94	0.983	7.05

From this table, the best HTL material is easily founded and it is PEDOT: PSS as its efficiency is 11.1 which is higher than the other two materials.

4.2.2 Optimization of ETL Material

Same as the previous one, three materials are also selected here based on their availability and cost efficiency. Those are ZnO, TiO_2 and n-C_{60}. Then the optimization is done by simulating these three in software and best one is selected for the final hybrid structure.

Table 4-3: Simulation result of optimizing ETL material

Tandem cell ETL Material		**Parameter**						
		V o c (V)	J s c (mA/cm^2)	FF (%)	Ƞ (%)	Max P (m W/ cm^2)	Voltage at max P(V)	Current at max P (mA/cm^2)
Zn O	**Zn O**	**1.42**	**12.18**	**64.06**	**11.10**	**11.10**	**0.993**	**11.74**
TiO_2	TiO_2	1.42	12.14	64.09	11.07	11.07	0.099	11.14
n-C_{60}	n-C_{60}	1.41	12.01	64.27	10.94	10.94	0.994	11.01

By analyzing the dataset from the given table, the best material for ETL is found directly which is ZnO. Because its efficiency is 11.1057 which is better than the others. So, it is selected as the final ETL material for hybrid structure.

4.2.3 Optimization for Interlayer Material

Here, Ag, Au, ZnO are initially selected for the optimization. Then the simulation is done just like the above ones for finding the most efficient interlayer for hybrid tandem structure.

Table 4-4: Simulation result of optimizing Interlayer material

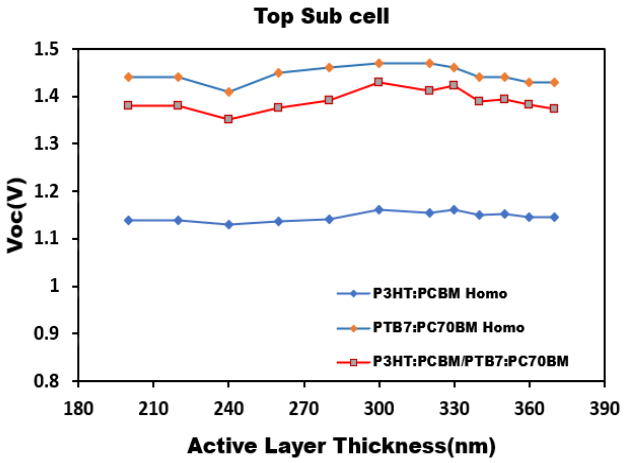
Parameter	Interlayer material		
	Ag	Au	Zn O
V o c (V)	**1.422**	1.406	1.39
J s c (mA/cm^2)	**12.186**	11.282	10.58
FF (%)	**64.06**	64.89	65.64
η (%)	**11.10**	10.29	9.60

So, after simulation the best interlayer in found and it is Ag as its efficiency is 11.10 which is better than Au and ZnO. Thus, it is selected.

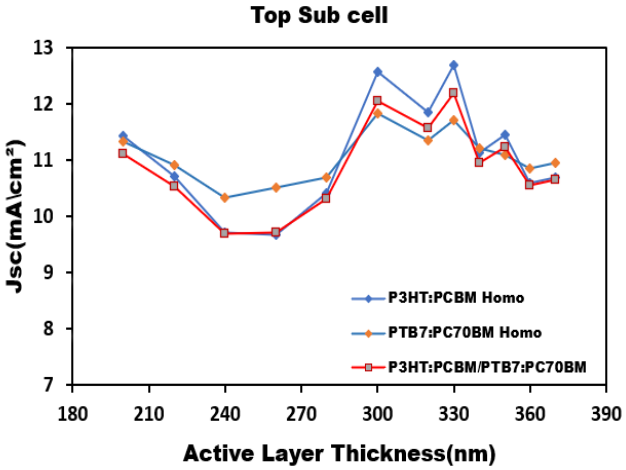
4.2.4 Optimization of active layer thicknesses

Two materials are selected as active layer of hybrid tandem structure. First one is P3HT: PCBM as top sub-cell and PTB7:PC70BM as the bottom one. At this point of work, their thicknesses are optimized by simulation as the efficiency of the device fluctuate by changing their thicknesses. So, perfect thickness of the active layer materials should be found. The range of thickness for active layers is usually 200 nm to 500 nm. The simulation is done in between them and the one with best efficiency is selected.

At first, the thickness optimization for top sub cell is done.



(a)



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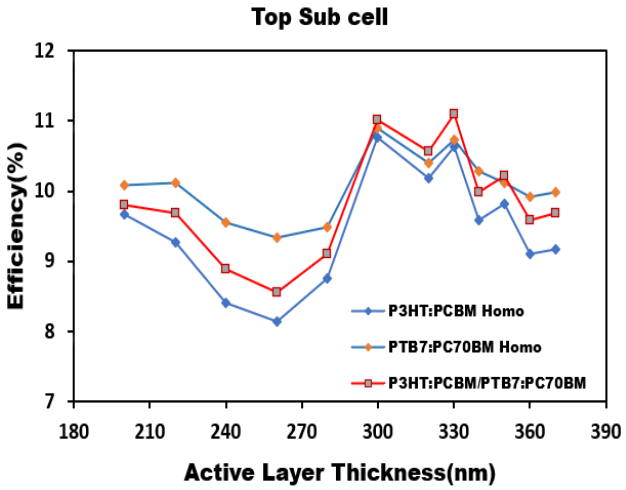

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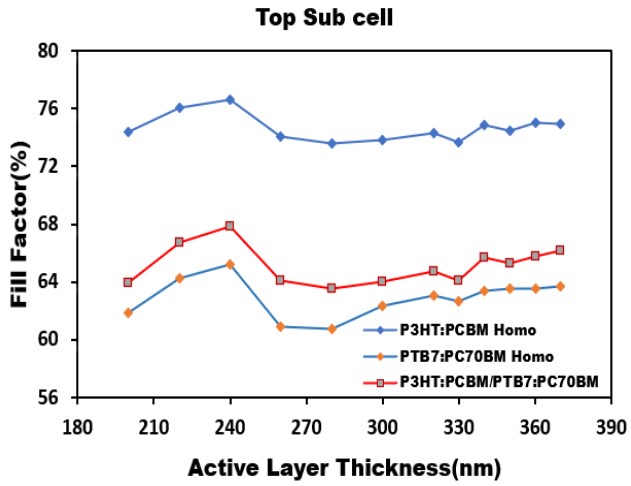

(d)

Figure 4-4 : (a) Voc vs top sub cell active layer, (b) Jsc vs top sub cell active layer, (c) Efficiency vs top sub cell active layer, (d) FF vs top sub cell active layer

There are four graphs for top sub-cell for four major properties which are V_{oc}, J_{sc}, efficiency and FF. Looking at the efficiency graph, the optimum point is found for 330 nm thickness of P3HT: PCBM material. So, this thickness is chosen for the final structure.

Here is the thickness optimization for bottom sub-cell.

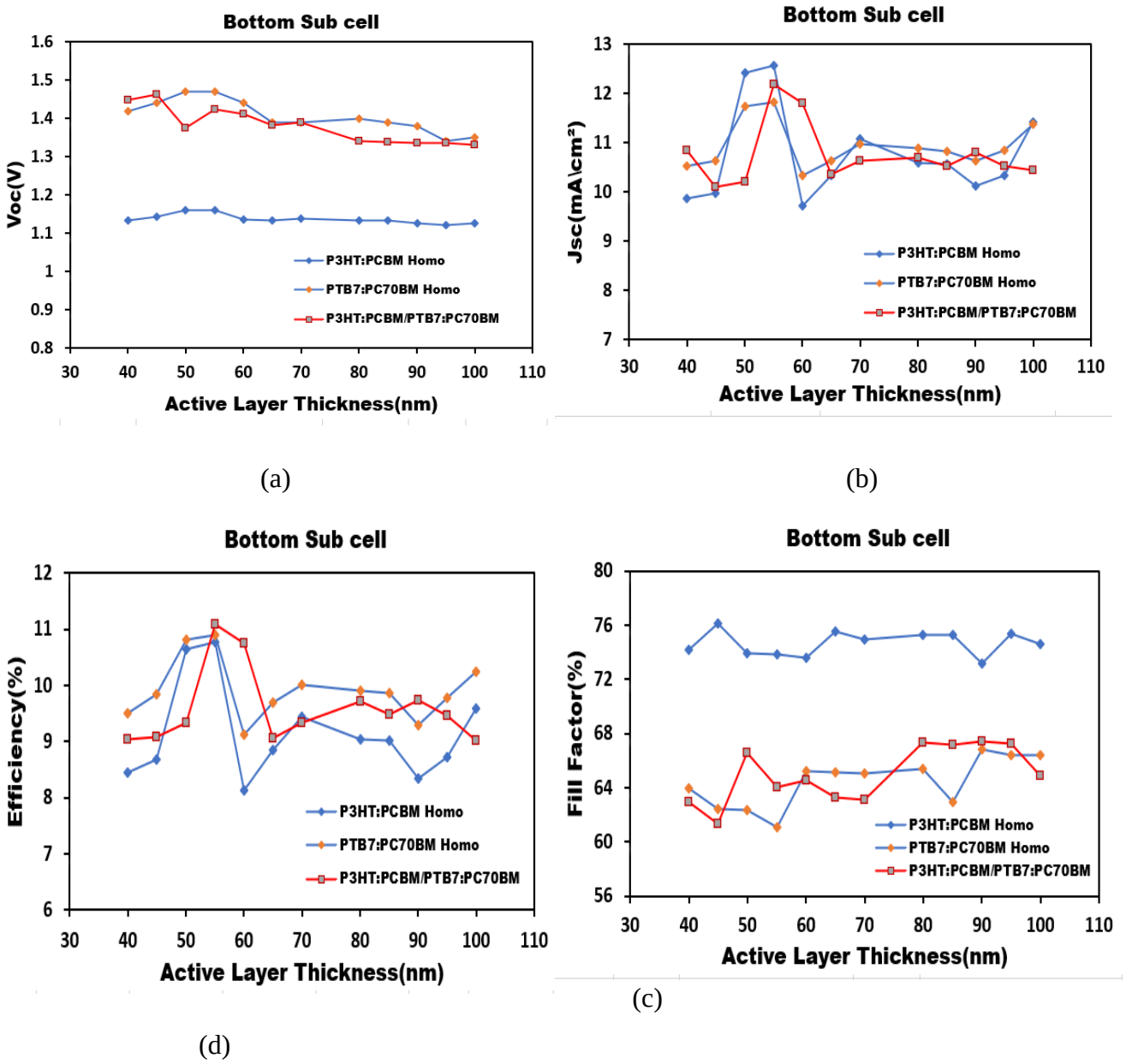

Figure 4-5: (a) Voc vs bottom sub cell active layer, (b) Jsc vs bottom sub cell active layer, (c) Efficiency vs bottom sub cell active layer, (d) FF vs bottom sub cell active layer

This time also for four types of properties such as V_{oc}, J_{sc}, efficiency and FF, four graphs are created. In the efficiency graph, the optimum point is found for 55 nm thickness of PTB7:PC70BM material. So, this thickness of bottom layer is chosen.

4.3 Final Result and Discussion

The materials for each layer of our final hybrid structure of tandem organic solar cell are determined by simulation. Not only the materials but also thicknesses of the layers are optimized by software. So, the final structure is found which given below.

Figure 4-6 : Final Hybrid Structure

This structure is simulated and different properties of it are found. These are the final properties of the work. The table is given below.

Table 4-5: Simulation result of optimized hybrid structure

Tandem cell Active layer Material	Parameter						
	V o c (V)	J s c (mA/cm^2)	FF (%)	Ƞ (%)	Max P (m W/ cm^2)	Voltage at max P (V)	Current at max P (mA/ cm^2)
P3HT: PCBM/PTB7/ PC70BM Hybrid	1.42	12.186	64.06	11.11	11.11	0.9938	11.174

From the table, final dataset is available. The final open circuit voltage is 1.42 volts, short circuit current density is 12.186 mA/cm^2, FF is 64.06% and final efficiency is 11.11%.

4.4 JV curve comparison between Homo and Hybrid Structures

There are three structures which are designed for tandem organic solar cell. Two homo structures and one hybrid structure. The JV curve characteristics are available. From this curve, its easily realizable why hybrid structure is more preferable.

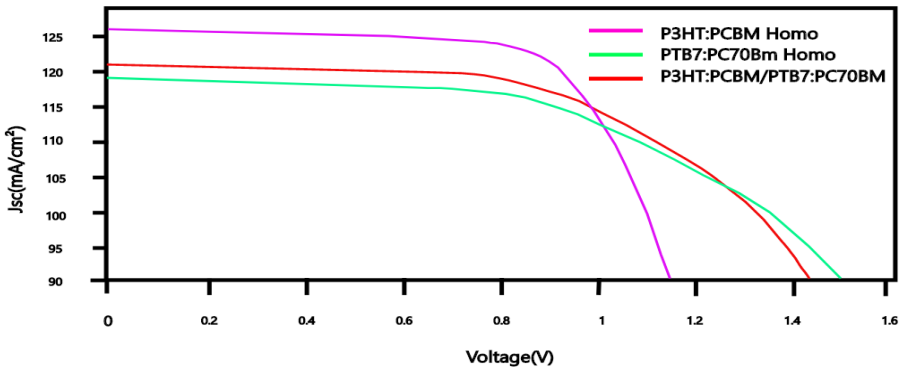

Figure 4-7 : JV curve comparison between homo and hybrid structures

From the graph, it's realizable that P3HT: PCBM homo structure has the highest short circuit current density and lowest open circuit voltage. The second homo structure which has PTB7:PC70BM as active layers material has the highest open circuit voltage and lowest short

circuit current density. These things are not expected as both V_{oc} and J_{sc} should be as high as possible. This property is got from the hybrid structure. Here both V_{oc} and J_{sc} are such that no property is so low. So, there is an equilibrium between these two properties which is expected. For these reasons, the best efficiency is found in hybrid structure, not in homo structures.

4.5 Comparison of different OSCs with the final result

The final efficiency of the work is 11.11%. In this part, the comparison of the final efficiency of this work with other organic solar cells is shown. The data set of other solar cells are found from different papers.

Table 4-6 : Comparison of different OSCs structure

SL no	Structure	Effficiency (%)
1	P3HT: ICBA/PBDTT-DPP [40]	8.62
2	a-Si:H p-i-n/PDTP-DFBT:PC71BM [41]	10.50
3	P3TEA: SF-PDI2/ P3TEA: SF-PDI2 [42]	10.8
4	P3TEA:FTTBPDI4/PTB7-Th: IEICS-4F [43]	10.5
5	PBDB-T-2F: TfIF-4FIC/ PTB7-Th: O6T-4F:PC71BM [44]	18.06
6	P3HT: PCBM/PTB7: PCBM	11.11

There are several works here. The highest efficiency is 18.06% which is higher than this work. But there are some shortcomings of their work. Firstly, the active materials they have used is more complicated than this works. These materials are not available in market. So, the fabrication of their work will be difficult. Moreover, the active layer materials of their work are so costly. But the materials which are used in this work are easily available, less costly and simple. So, they are chosen for this work considering overall situations though they have lesser efficiency.

Chapter 5

Practical Industrialization of Organic Solar Cells

5.1 Introduction

Different kinds of fabrication processes of organic solar cells are described in this chapter. These are for practical industrialization of OSCs. There are several methods which are being followed for this purpose. From them, spin coating, inkjet printing, roll to roll deposition and doctor blade are famous. Also, the problems which are associated with the industrialization process are discussed in this chapter.

5.2 Difficulties of Industrialization process

Firstly, there are different kinds of layers used in the experiment. Among them HTL, ETL, ITO etc. are there. The problem is, the materials which are used in this purpose has faster degradation life cycle[45].This thing is happened for some reasons. The materials used for HTL, ETL, ITO are sensitive for air. Second one is that when the size of active area is greater, the power conversion efficiency will be dependent on active area. It's because of the inflamed electrical resistive losses and defects.

Moreover, the device performance is dependent on different issues. Crystallinity, segregation, topology of active layers is among them. Because exciton separation and charge mobility are dependent on a parameter. And it is the domain's size[46].The morphology got from the result is influenced by some properties. Thermodynamics of solution, solvent nature, solubility of reactants are among them. These things are also further influenced by the additive's use[47]. Furthermore, for gaining higher efficiency more, solution ageing and formulation of ink is important[48]. So, for these reasons the process of fabrication for industrialization from the lab module is not an easy task. There are some difficulties in it.

5.3 Different techniques of fabrication for industrialization

As previously told in the introduction section that different kinds of techniques are used for fabrication of organic solar cells. In this part those techniques will be discussed.

5.3.1 Inkjet Printing

In addition to traditional graphic printing methods, IJP has been used as a production tool in the last few years in advanced Technology Fields. This technique has been applied to devices such as narrow film transistors, LEDs , memory appliances, organic solar cells, conductive structure, sensors and biologic implementations[49].Inkjet printing facilitates the scattering of thin films from liquefied or smeared materials on any substrate in a reproducible behavior. The exact proper placement of each picolitre droplets expelled from piezoelectric-controlled parts is an advantage that enables exact digital modeling, which, in turn, contributes to efficient digital patterning. In addition, contamination is minimized since inkjet printing is a non-contact deposition process. Typical side-resolution in the size of the micrometer can be accomplished using lab-scale printers. The speed of the processing depends on the number of printing jets. At present, commercially available tools can be used concurrently up to 1024 jets that allow printing at speeds of 500 mm/s[50]. In addition, the compatibility of inkjet printing with the R2R processes make it industrially important.

5.3.2 Screen printing

The process of screen printing is a customary concealing strategy which permits 2D designing and can be utilized for both sheet-to-sheet and roll-to-roll frameworks. The main attribute of this strategy is that colors should have viscosities in the request for Pa·s which are not viable with a significant number of the colors utilized for OPV. In any case, screen printing is a fundamental apparatus in a portion of the mechanical cycles right now used to create reversed OPV modules in light of the fact that PEDOT: PSS and silver can be concealed by this method. The working system depends on the utilization of a material screen which is recently coated with an UV relieved emulsification on the whole rear with the exemption of the districts where the example should be concealed. A specific measure of glue is set on the curtain and a wiper is used to make it to channel through the curtain onto the surfactant. The screen-printing glues can be relieved by temperature toughening or upon UV openness. This kind of method delivers

effortlessness of utilization and good throughput, having the option to be incorporated in a move to-move framework. Additionally, business glues are effectively accessible at lower costs than those for inkjet printing dodging a significant work of plan Regarding the definition, the thickness needed, between 3 to 20 Pa·s, makes it hard to press by this strategy ingredients like PCBM, P3HT and ZnO. Other essential viewpoints identified with detailing are the micrometric depth of the pressed layers and the requirement for diluents with low dissipation rate to dodge material drying in the screen. There exist not many models in writing of screen printed OPV modules by utilizing thermolabile solvents which give the ink sufficient thickness and which have low dissipation movements[51.52] For above reasons, screen printing is all the more frequently utilized as a correlative printing procedure to complete the gadgets with silver, particularly on account of space pass on based cycles[53].

5.3.3 Doctor Blade

On account of doctor blade, the ink is kept onto the substrate by methods for a covering blade that is put at a fixed separation from the surface. The sharp edge moves straightly over the substrate at a 15-steady speed, spreading the ink and creating a wet film which dries because of the dissolvable evaporation. The film is then the aftereffect of the blend of ink properties and blading boundaries. Hence, film harshness and morphology, surface wettability, and the inclusion of the substrate are controlled by the arrangement and the substrate properties along with the distance among substrate and edge, its speed and the temperature of the substrate. The ideal thickness of the layer relies upon its capacity; in this manner, charge transport layers should be adequately slim to have agreeable versatility esteems while adequately thick to dodge pinholes though the dynamic layer should amplify light ingestion and transporter age and transport. Doctor blade is a simple strategy to grow the dynamic territory of the gadgets with low material waste. Truth be told, it is effectively adaptable to a reel-to-reel framework where it is known as blade over-edge covering. For this situation, the blade is fixed and the moved substrate moves. In any case, it doesn't take into account designing and the thickness of the ink should be sufficiently high to abstain from releasing or running back on the roll. Hence, with such prerequisites this strategy has been infrequently utilized in the creation of solar cells[54,55].

5.3.4 Slot Die

The slot die procedure utilizes a tempered steel printing head took care of with an ink which is flown utilizing a legitimate siphoning system. The ink experiences a space, which breadth is characterized by a cover what isolates the two head parts, and collapses onto the surfactant. This framework can be implemented both to sheet-to-sheet and ceaseless roll-to-roll frameworks. In the last instance, enormous rear concealing and upscaling preparing are conceivable as web velocity of a few $m \cdot min^{-1}$ are permitted being the as it were impediment the way that covering gets temperamental at high speed[56]. Additionally, space pass on permits direct designing in type of stripes by utilizing covers with free districts where the ink can stream. The cover assumes a significant part as its depth can fluctuate in the scope of several microns relying upon ink consistency which can go between a couple of mPa·s and hundreds mPa·s. One significant viewpoint to envisage is that meager covers are more inclined to twist by it taking care of and the veil status corruption can prompt undesired consequences for the printing interaction. Additionally, the veil must be planned and delivered for each new example.

5.4 Determination of Printing Method

The determination of a specific method is controlled by the attributes of gadget, so boundaries like shape, construction, and kind of cationic or the velocity of statement should be initial considered. In a subsequent advance, the inks should be obliged to the chose method. Consequently, the thickness along with the vanishing pace of the dissolvable and the after-affidavit states should be adjusted. The strong substance, dissolvable behavior and the speed of statement decide the energy of absorbing and the subsequent morphology of the film which is one of the main components administering gadget execution. Simultaneously, the usability settles on specialist edge the strategy of decision for quick arrangements though inkjet printing, screen printing and space bite the dust affidavit offer extraordinary example definition.

Chapter 6

Summary and Conclusion

6.1 Overview of the Work

In chapter-1, Introduction part is written. In this chapter, the basic ideas of solar cells and organic solar cells are discussed. The background of solar cells, types of OSCs, principle of operations, drawbacks of OSCs are also explained. Moreover, some other issues are also written such as the software which is used in this work, materials used in different layers and some previous research works. This chapter is actually the starting of the book and contain the basic ideas of organic solar cells.

In chapter-2, some topics of chapter-1 are explained in detail such as working principle of OSCs, it's characterization, materials, basic structure of organic solar cells, the initial design etc. These topics are very essential for understanding the organic solar cells as this kind of solar cells are not so popular and different than other conventional solar cells. So, these topics are discussed in detailed so that anyone can relate with what is going on here.

In chapter-3, improvisation of the initial design is done. The initial design is discussed in chapter-2. For the improvisation of the previous design, a new kind of organic solar cell is introduced named as tandem organic solar which is different in nature, structure from normal organic solar cells. Efficiency is increased with a good amount by using these cells. This chapter is actually all about tandem organic solar cell, it's basic structure, different types of tandem cells, it's characterization and so on.

In chapter-4, the result and simulation part of this work is done. The simulation of each design, it's result, comparison between different structures is also included there. After finding the final result, a comparison of this work's result with other work's results are also showed. The explanation is also given why this result does not have the highest efficiency among other works.

In chapter-5, the fabrication of organic solar cells for industrialization is discussed. Different kinds of fabrication methods are explained in this chapter. The problems regarding the fabrication processes are discussed too. There is also a discussion comparing the fabrication processes.

6.2 Major Contribution of the Work

A process is being followed from the very beginning of the work. First, regular organic solar cell has been designed. But the problem in conventional organic solar cell is that the efficiency of the solar cell is very small in amount. They are in range of 5% to 6% which is not enough actually.

So, the main target is to gain more efficiency. For this reason, the tandem organic solar cell is introduced. Then analyzing the basic structure of this kind solar cell, a perfect structure is designed for this work. While designing the structure, many things are kept in mind such as the materials used in this thesis have to be available and cost effective. Any material which is complex or rare, cannot be included. Specially, for the active layer materials. P3HT: PCBM and PTB7:PC70BM, these two materials are used as active layers in the whole work. The reason behind choosing them is obviously their availability and cost effectiveness. After choosing the material for active layers, other materials for different layers like HTL, ETL, Interlayer are also determined. For finding the perfect and effective ones, numerical simulations are done many times in GPVDM software and the ones with best efficiencies are taken.

Also, there are two types of tandem organic solar cells. HOMO and HYBRID tandem organic solar cells. Both types of tandem organic solar cells are designed and simulated and found that HYBRID tandem organic solar cells are the most effective. So, for the final structure, HYBRID organic solar cell is selected. After simulating the final structure, the best efficiency is found (11.11%).

A comparison is done between this work with other works. In a recent paper, their efficiency is about 18.06% which is greater than this. The problem is their active layer materials are complicated, rare and not cost effective. If they want to fabricate them for industrialization, they will face problem because of the absence of availability of the materials as well as high prices. If the material price is high overall cost for industrialization will be much higher. To overcome this kind of problem, available and cost-effective materials are used in this work though the efficiency is little bit lower than theirs.

So, these are the major contribution of this work.

6.3 Conclusion

We have made our design as simple as possible so that it can be implemented easily in practical situation. As organic solar cells are not so popular for the lack of their efficiency, our future work should be about improving their efficiency. But obviously, in this case we have to be careful about using the active layer organic materials. The materials should be simple and cost effective just like we used in this work.

6.4 Future Work

Present day savvy structures are required to contain a complex of connecting frameworks, stretching out past the warming, ventilation, and cooling frameworks normally found in present structures. Frameworks for overseeing illumination, safety and wellbeing, energy interest, and personalization highlights will turn out to be considerably more typical. The utilization of energy-gathering surfaces like glasses in metropolitan conditions is relied upon to be a primary empowering agent for the bigger sending of the different IoT implementations that at present depend on power from the network or from batteries with restricted lifetime and require continuous support. Instances of these remote arrangements are sensors and little mechanized frameworks for ventilation and concealing[57,58].

In the metropolitan setting new applications are relied upon to arise with more extensive appropriation of keen leaving meters, unified traffic-light frameworks, dynamic shows, or even the administration of self-sufficient vehicles. One fascinating methodology exploits the less heavy characteristic of OPV modules through reconciliation into transport covers or other framework to help the advancement of "associated urban areas". Such applications not just increment customer wellbeing by giving capacity to lighting during the evening, yet additionally empowering different gadgets, for example, sensors for examining air characteristic or temperature, associated equipment for constant traffic checking, or electronic charging stations

While a basic standard light range has been created for outside applications, a particularly standard is absent for indoor light tests because of the enormous varieties in light sources like bright light, LED, brilliant lights, sun coming through window[59]. The most generally utilized light sources in home or office conditions are fluorescent lights or white LEDs, and accordingly they are the most normally utilized lighting for specialized investigations. Their illuminance is for the most part in the locale of 200 lux (front room climate) to 1000 lux (office climate),

relating to a light force of around 100 to multiple times lower than 1 Sun condition. Under indoor conditions, low force indoor gadgets, for example, remote sensor network hubs devour power in the area of few mW[60]. Grounded photovoltaic advancements, for example, silicon sun-based cells have effectively been appeared to give sufficient force under such low-light levels. The utilization of photovoltaic advances in this sort of climate is promising for the creation of low support gadgets, as well as being more harmless to the ecosystem than business batteries. Thus, various indoor items have arisen inside the most recent couple of years utilizing photovoltaic advancements, including a few that coordinate OPV[60,61].

In corresponding to these endeavors, a few electronic wearables and versatile items have been produced for business use in the course of recent years, making ready for IoT advances. Markets where these advances are required to have an effect incorporate medical services (diagnostics, health checking), garments, increased reality, wellness, and safety. Business models in which OPV has been utilized in outside stuff like tents, knapsacks and waterproof coats. Keen pack, which interfaces by means of Bluetooth to a cell phone, controlled by OPV. The pack features approaching messages and calls and sounds a caution if the telephone is given up.

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