

Performance Analysis of Third-Generation Organic Solar Cells for High-Efficiency Renewable Energy Harvesting and Sustainable Biomedical Device Power Systems

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ABSTRACT

High costs and very little portability have become issues with solar panels. The new third generation solar cells that aims to overcome this disadvantage is the organic solar cells. Even though, an entirely different set of challenges has risen with this new technology, more efficient and stable structures of the same are being developed. In this paper, a basic organic solar cell and a bulk hetero junction solar cell have been analyzed in terms of their fill factors and efficiency.

KEYWORDS: Organic solar cells, conductive polymers, J-V characteristics, fill factor, efficiency.

1. INTRODUCTION

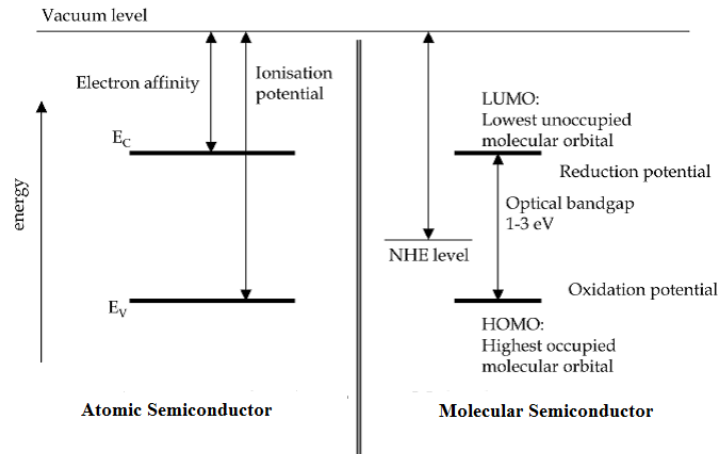
Renewable energy is the need of the hour and one of the most abundant sources of energy is the Sun. Conversion of sunlight into electrical energy is known as a branch called photovoltaics. Today, silicon based solar cells are leading the photovoltaic market, with power conversion efficiencies approaching 25% [1]. But the prices of silicon panel based power generation are still not competitive with other conventional power generation techniques. The third generation solar cell technology specifically characterized by low-cost solution processing technique is the organic solar cell (OSC) technology.

Organic photovoltaic research within the last decade has gained considerable momentum due to the discovery of new table polymers capable of selective absorption of light energy. These organic polymers normally exist in liquid form at room temperature giving an added advantage of forming thin films when compared with the larger and heavier silicon panel solar cells.

The discovery of the conductivity of polymers in 1977 by Shirakawa, MacDiarmid and Heeger [2] has enabled the use of conjugated polymers in solar cells and more generally in organic electronics. In solar cells based on organic materials, light absorption results in the formation of excitons at the molecular level. An exciton in an organic semiconductor can be considered as a tight coulombically bound electron-hole pair. Due to its electrical neutrality and the strong binding energy between the hole and the electron it can be regarded as an exciton.

The energy levels in a molecular semiconductor material can be related to the energy levels of an atomic semiconductor as shown in figure 1. In molecular materials, electrons move from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO) after absorbing light as packets of energy or photons, similar to the movement of electrons from valence band (E_V) to conduction band (E_C) with absorption of energy. In an atomic semiconductor, the electron affinity is the energy gained when an electron is transferred from the vacuum level to the conduction band edge. Similarly, in molecular semiconductor materials, the normal hydrogen electrode (NHE) level is the energy difference from the HOMO level to the vacuum level. The band gap difference between HOMO and LUMO can vary between 1-3eV in organic polymers.

Figure: 1



Overview of energy levels in Atomic and Molecular semiconductors[3]

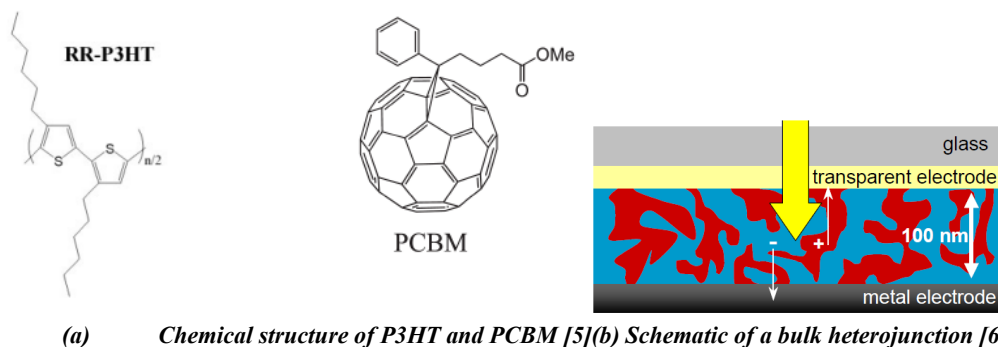
But with the advantages listed above, they also have the following shortcomings. Separation of electrical charges is very poor and it limits the efficiency of organic solar cells to a low value of around 10% [4]. These organic polymers also tend to be very sensitive to normal atmospheric conditions. Hence, they degrade much faster when compared to silicon solar cells.

2. PRINCIPLE OF ORGANIC SOLAR CELLS

A. Photoactive layer of OSCs

The region of an OSC that absorbs light energy is called the active region or the photoactive layer. It is similar to the intrinsic region of a semiconductor based p-i-n solar cell where the light absorption takes place. In OSCs, the photoactive region is made of different kinds of organic polymers. The most commonly used organic polymer for the photoactive layer is P3HT:PCBM [5]. It is a blend of poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl C₆₁-butyric acid methyl ester (PCBM) and is the most efficient fullerene derivative based donor-acceptor co-polymer. The structure of P3HT:PCBM is as shown in figure 2(a). PCBM is a fullerene derivative. Because of high hole mobility, it plays the role of electron acceptor in many organic cells. P3HT is a kind of conducting polymer. It is the excitation of the π -orbit electron in P3HT that gives the photovoltaic effect in the blend.

Figure: 2



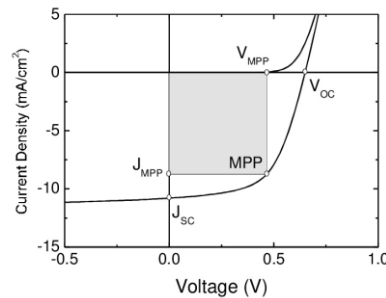
(a) Chemical structure of P3HT and PCBM [5] (b) Schematic of a bulk heterojunction [6]

The bulk heterojunction (BHJ) is presently the most widely used photoactive layer. The name bulk-heterojunction solar cell has been chosen, because the interface (heterojunction) between both components is all over the bulk. As a result of the intimate mixing, the interface where charge transfer can occur increases enormously. The exciton, created after the absorption of light, has to diffuse towards this charge-transfer interface for charge generation to occur. The diffusion length of the exciton in organic materials, however, is typically 10 nm [7] or less. This means that for efficient charge generation after absorption of light, each exciton has to find a donor-acceptor interface within a few nm, or otherwise it will recombine. An intimate bi-continuous network of donor and acceptor materials in the nanometer range can suppress exciton loss prior to charge generation. To date, the best material combination for a BHJ organic solar cells is a blend of a π -conjugated polymer used as donor material and a fullerene derivative, [6,6]-phenyl-C₆₁-butyric acid methyl ester (PCBM), used as acceptor material. The BHJ schematic is shown in figure 2(b).

B. Efficiency Calculation

To study the performance of a solar cell, the current density-voltage characteristic (J-V curve) in the dark and under illumination is measured [8]. Figure 3 shows a typical J-V characteristic. In the dark, the solar cell behaves like a diode and the current can go through the device only in forward bias. Under illumination, the curve is shifted downwards. The difference between the current measured in the dark and under illumination is the photocurrent that has been generated by the solar cell. Along the J-V curve under illumination, the power density at the maximum power point (P_{MPP}) can be found where the product of current density and voltage is maximal.

Figure: 3



Typical J-V characteristics of a Solar Cell [8]

A solar cell is characterized by three parameters: the open-circuit voltage (V_{OC}), the short-circuit current density (J_{SC}) and the fill factor (FF). The FF defines the quality of the J-V curve under illumination and is representative of how easily the charges can be extracted from the cell.

$$FF = \frac{P_{MPP}}{J_{SC} \cdot V_{OC}} \quad (i)$$

The power conversion efficiency of the solar cell is defined as the ratio between the maximum output power and power of the incident light.

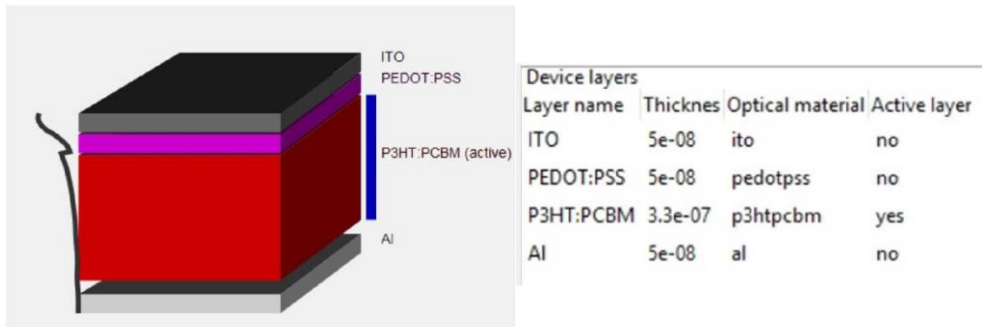
$$\eta = \frac{FF \cdot J_{SC} \cdot V_{OC}}{P_{light}} \quad (ii)$$

3. STRUCTURE AND SIMULATION

Two different OSC structures were chosen for simulations. They were simulated under different suns or illumination and the efficiencies were tabulated from its current-voltage (I-V) characteristics. The simulations were done using the open source software - general purpose photo voltaic device model (GPVDM) [11].

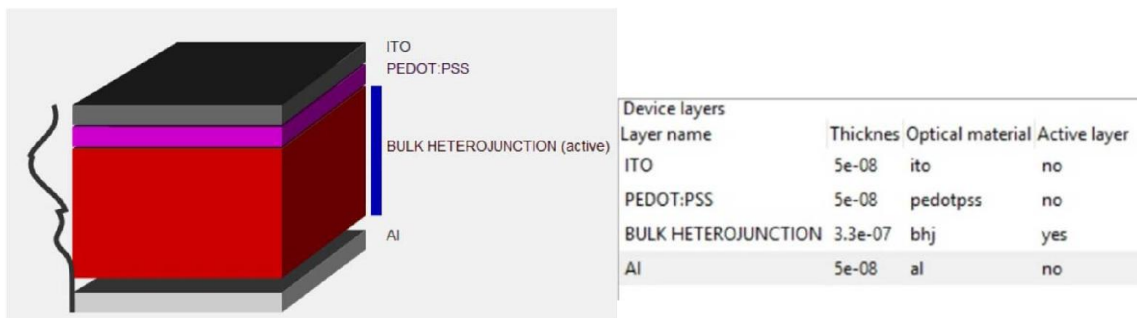
The difference in the two structures is in their active layer. In the basic structure, the active layer chosen for analysis is an organic polymer P3HT:PCBM. The structure is as shown in figure 4. The active layer for the second structure is a BHJ with all other layers remaining the same. The structure is shown in figure 5.

Figure: 4



Basic OSC structure with active layer P3HT: PCBM

Figure: 5

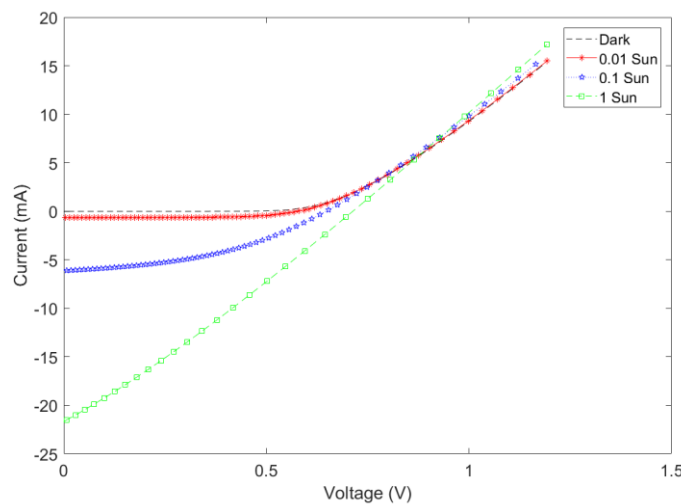


BHJ OSC structure

4. RESULTS AND DISCUSSION

The figure 6 below is the I-V graph of simulated basic OSC structure with active layer P3HT: PCBM. The efficiency for different illuminations was calculated and tabulated in table 1.

Figure: 6



I-V characteristics of basic OSC structure

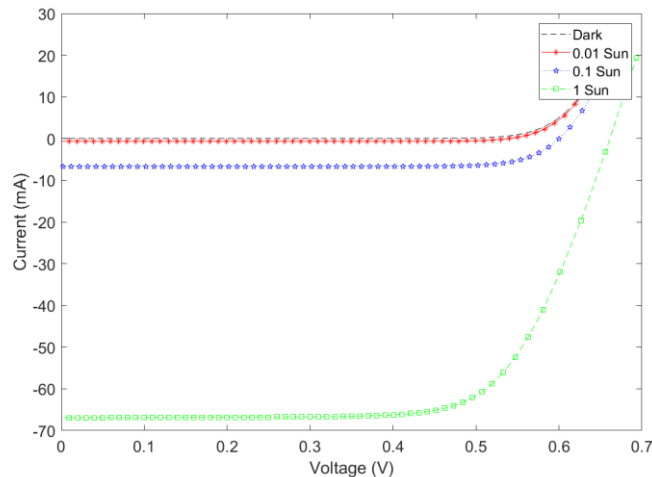
Table 1. Efficiencies for different solar irradiances: Basic OSC

Solar Irradiance	Extracted values			
	Voc(V)	Isc (mA/m ²)	Fill Factor (FF)	Efficiency (η)
0.01 Sun	0.5784	-0.66	63.83	7.71
0.1 Sun	0.6470	-6.12	41.61	5.19
1 Sun	0.7132	-21.99	26.98	1.33

Table 1 shows lower efficiencies for higher suns. This is due to the fact that the entire excitons being created by illumination is not being collected at the contacts for current creation. They recombine faster thus showing a decrease in efficiencies at higher suns.

I-V characteristics of simulated BHJ OSC structure is plotted in figure 7 and its efficiency is tabulated in table 2.

Figure: 7



I-V characteristics of BHJ OSC structure

Table 2. Efficiencies for different solar irradiances: BHJ OSC

Solar Irradiance	Extracted values			
	Voc(V)	Isc (mA/m ²)	Fill Factor (FF)	Efficiency (η)
0.01 Sun	0.5398	-0.672	80.65	9.22
0.1 Sun	0.6002	-6.719	80.03	10.17
1 Sun	0.6613	-66.951	69.55	9.699

The efficiency values were found to be much better when compared to that of classical OSCs. This indicates that more no. of excitons are being dissociated in a BHJ layer. To dissociate an exciton in organic materials, the charge transfer interface should be separated by a distance comparable to that of an exciton diffusion length. The exciton diffusion length is in the order of ~ 10 nm in organic materials. In a BHJ, due to random mixing of donor and acceptor materials, the donor-acceptor interface is separated at a nanometer scale. Hence, better exciton dissociation has become possible at higher suns and the recombination was reduced to a large extent thereby improving the efficiency using BHJ as photoactive layer.

5. CONCLUSION

In this paper, a comparative study on two different OSC structures has been done and efficiencies of these structures were calculated for different irradiances. It was found from the simulations that BHJ was a much better active layer when compared to the other classical active layers. This is because BHJ aids in better exciton separation when compared to other organic polymers.

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