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The Effect of Coating Parameters of Active Layer on the Performance of Polymer Solar Cells

Esma Yenel[1]*

[1]Konya Technical University, School of Technical Science, Department of Electricity and Energy, Konya Turkey
*esmayenel@gmail.com
*Orcid: 0000-0003-1348-6399

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Abstract

In this study, Glass / ITO / PEDOT / Polymer / Al organic solar cell structures were obtained by using glass/indium doped tin oxide (Glass/ITO) transparent metal oxide substrates, PEDOT:PSS and P3HT:PCBM polymer photoactive layer and their performance depending on spin rate and coating technique were investigated. The polymer layer was coated using the spin coating method. Al metal was coated by the physical vapor deposition method. By keeping the concentration of the photoactive layer constant, the effects of different spin coating rates, beside static and dynamic coating technique on the power conversion efficiency of the cells and their stability were compared. Electrical characterization of organic solar cells was performed under a solar simulator in a glove box system. By applying voltage between -0.5 V and +1.5 V, I-V (current-voltage) measurements of the solar cells were taken in the light and dark. The power conversion efficiencies of organic solar cells coated at 800rpm, 1000rpm and 2000rpm spin coating speeds, respectively, were observed to be 2.34%, 2.08% and 1.98%. When the average efficiency values are considered, static coating at 800 rpm gives more reproducible results in comparison with the other average efficiency values. The average efficiency values for static coating at 800 rpm is observed to be %2.

Keywords: Energy, Organic solar cell, Photovoltaic, Polymer solar cell,

1. Introduction

Recently organic solar cells have gained great attention due to their easy fabrication, low cost and flexibility. Organic photovoltaics consist of two organic-based materials compressed between two metal electrodes. The most common type of device is a combination of the donor (p) and acceptor (n) materials. In addition, it is possible to change the chemical structures of the materials, as well as to increase the efficiency with additional materials. In normal type organic solar cells, active P3HT:PCBM layers are produced between a transparent ITO (indium tin oxide) or FTO (fluorine tin oxide) glass and an Al back electrode.

While simple photovoltaic (PV) devices based on organic materials have limited power conversion efficiency (PCE), typically below 0.1%, over time, including dye/dye, polymer/dye, polymer/polymer, and polymer/fullerene blends showed higher efficiency and have become interesting for researchers. Due to the high electron carrier capability of fullerene, polymer/fullerene mixtures have become a subject of interest in recent years [1]. In polymer solar cells, poly (3-hexylthiophene) (P3HT) and phenyl C61-butyric acid methyl ester (PCBM) are the most widely used materials with improved efficiency. PCBM is a fullerene derivative material. Due to its high electron mobility, it is used as an acceptor material in organic solar cells. P3HT is a commercially available and has a wider absorption spectrum than polyphenylene vinylene (PPV) derivatives that make them another widely used material in this technology.

In conventional organic solar cells, poly (ethylene-dioxythiophene) (PEDOT) solution is coated on the conductive substrate. PEDOT is a thiophene derivative but has poor solubility in water. It is mixed with polystyrene sulfonate (PSS) to increase the solubility in water and it becomes a proper form for the solution process. Combining with PSS also provides high conductivity which is a requirement for organic solar cells. An active layer is coated on PEDOT:PSS film which improves the quality of the ITO or FTO coated surfaces. The active layer is generally composed of polymer-fullerene derivatives. The typical structure of organic solar cell is shown in **Hata! Başvuru kaynağı bulunamadı.**.

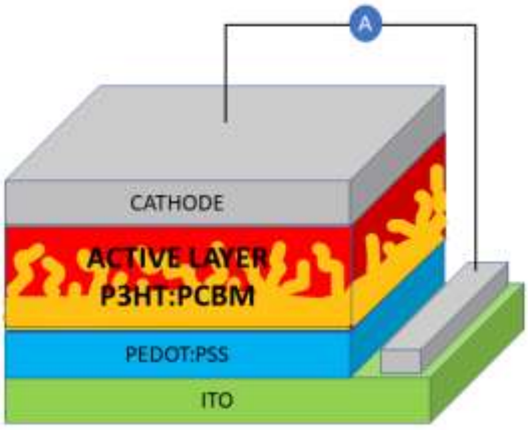

Figure 1. Schematic presentation of a typical organic solar cell.

Photocurrent generation in polymer solar cells consists of 4 steps: light absorption, exciton diffusion, separation of excitons into charge carriers, and charge collection. First, the incident light is absorbed by the active layer and excited molecules are formed in the active layer. The excitations spread in the active layer and dissociate at the interface with different electron affinities to form free charge carriers. Finally, the charge carriers are transported by moving towards the anode and cathode due to the chemical potential difference [2]. There are generally 2 different types of structures for photoactive layer. The heterojunction structure is generally formed by coating the mixture of donor-acceptor materials on a substrate as a mixture. Unlike bulk inorganic semiconductors, organic semiconductor materials do not directly produce free charge carriers by light absorption, but strongly form electron-hole pairs called excitons [3]. Since the exciton diffusion length is typically around 10-20 nm in conjugated polymers, the optimum distance of the exciton diffusion length in donor-acceptor (D/A) interface must be approximately 10-20 nm. For this reason, in bulk-heterojunction structure active contact area, its length and film structure play an important role in charge separation and transport [4]. Therefore, the size of the active contact area has critical importance on performance. An ideal donor-acceptor configuration should be perfect for efficient exciton dissociation and charge transport (Figure).

The size of the active contact area depends on the optimum microphase separation. While microphase separation can usually be achieved by heat treatment, some methods can be applied during the production process to facilitate this separation. Microphase separation occurs due to the tendency of p and n-type (P3HT and PCBM) semiconductor molecules in mixture to come together. However, the duration of the heat treatment and the applied temperature are important parameters and may vary depending on the ambient conditions. It has been shown in previous studies that the mixing ratios of semiconductor, thermal annealing and type of solvent play a critical role in the performance of organic solar cells [6]. Zhao et al. [5] worked on the 70 nm thick P3HT:PCBM (1:0.8) and exposed them to 120, 130, 140, 150 °C for different periods of time. While the efficiency was 0.74% in the cell without any heat treatment, it was observed that the efficiency increased to 2.54% after 3 minutes of heat treatment at 130 °C. On the other hand, the cell with a thickness of 250 nm of the active layer, the highest value was obtained at 150 °C for 3 minutes. Another parameter that affects solar cell performance is the P3HT/PCBM solvent. P3HT/PCBM dissolves well in solvents such as toluene, chloroform, chlorobenzene. However, solvent evaporation during spin coating is an important factor. Wang et al. examined the effects of mixtures prepared with different solvents and observed that 1,2-dichlorobenzene and chlorobenzene solvents were the best compared to other solvents [7]. They even found very good results with a mixture of two solvents [8].

However, active layer thickness is also a critical parameter and directly affects cell efficiency. Iakobson et al. reported that the thicker the photo active layer, the larger short circuit current (Jsc) and photon to current conversion efficiency (PCE). PCE increases more than twice within the studied range[9]. Further increase of the photo active layer thickness leads to increase in roughness. Light harvesting ability increases with increasing film thickness but it results in larger charge diffusion lengths and thus recombination losses [10–12]. Here we have to notice that thicker films do not mean better performance. Because there is a thickness limit for charge diffusion length and optimum thickness must be considered for the best efficiency. Farrokhifar et all showed that more than 90 nm thickness FF value dramatically decreases due to more and more light harvesting which leads an increase of hole density. As well-known larger holes and excitons leads lower mobility of charge carriers and thus efficiency decreases [10].

In addition to the charge diffusion distance, thickness is also important in microphase separation. On the other hand, the morphological structure of the film is another factor and varies depending on the coating speed and technique.

In this study, besides the coating speed of the active layer, the effect of dynamic or static coating on the performance was investigated. The reproducibility tests of the prepared solar cells were carried out and optimum production conditions were determined over the average efficiency values.

2. Materials and Methods

2.1. Preparation of Solar Cells

ITO coated glasses, which allow light to pass through the active layer easily due to their transparency, are cut in 1.5 cm x 1.5 cm lengths. All glasses were washed with Hellmanex solution in an ultrasonic bath for 10 minutes. Then washing process was continued with water, acetone and propanol, respectively. The cleaned glasses were dried with nitrogen gas and exposed to oxygen plasma for 5 minutes.

PEDOT:PSS was filtered before coating. P3HT:PCBM ratio was adjusted to be 1:0.7. P3HT:PCBM was prepared by dissolving them in chlorobenzene/dichlorobenzene (1:1) solvents. It was incubated overnight on a magnetic stirrer at 45°C. PEDOT:PSS (70 µl) was statically coated for 40 seconds at 4000 rpm. PEDOT:PSS coated glasses were dried at 120 °C for 10 minutes. Coating was carried out by statically or dynamically by dropping 50 µl of 2% P3HT:PCBM solution on PEDOT:PSS coated ITO glass. P3HT:PCBM (cb/dcb) solutions were dynamically and statically coated with three different coating speeds of 800, 1000, 2000rpm under the same conditions. Static coating refers to dropping the perovskite solution onto film before spinning while dynamic refers to dropping the solution during spinning. The coated films were heat treated at 150 °C for 10 minutes. Finally, 80 nm Al electrodes were coated by physical vapor deposition technique under 5x10-6 torr pressure with an evaporation rate of 0.1 A°/s - 5 A°/s. Figure 3 shows fabrication steps for organic solar cells. After the steps in Figure 1, solar cells with ITO/PEDOT:PSS/P3HT:PCBM/Al concepts were fabricated.

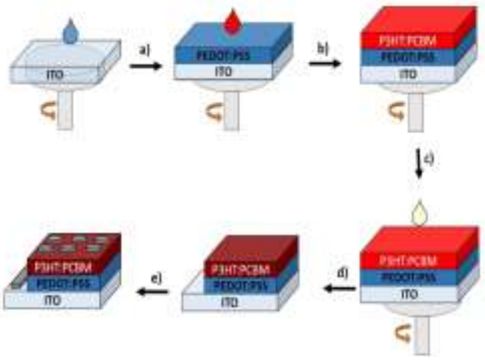

Figure 1. Scheme of preparation of organic solar cells

2.2. IV characterization of solar cells

Electrical characterization of organic solar cells was carried out in the glove box system (from MBraun company) under a solar simulator (Atlas, AM 1.5) by applying voltage between -0.5 V and +1.5 V, I-V (current-voltage). The results were calculated with home-made software. The software provide us all required data such as efficiency, FF, I_{sc} and V_{oc} etc for graphs. Measurements of the solar cells were taken in the light and in the dark. I-V results were evaluated according to the coating speed and static or dynamic coating technique by keeping the active layer mixing ratio and temperature constant.

3. Results and Discussion

Thin films of P3HT/PCBM (1:0.7) prepared in dichlorobenzene (DCB) and chlorobenzene (CB) were prepared separately at 800, 1000, 2000 rpm and compared with each other. Compared to coatings with high rotational speed and coatings with low rotational speed, the film thickness of the higher spin rates will be thin. Thin films absorb light less than thick films [13]. In this study, it is thought that since the cells coated with 800 rpm will be thicker and thus they will absorb more light. A photo of organic solar cells coated in different thicknesses prepared for this work is given in Figure **2**.

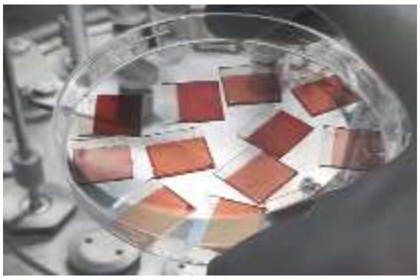

Figure 2. The photo of fabricated solar cells (except for top metal contacts)

The IV graphs of fabricated solar cells are given in Figure 3. In this graph, the best performance for each concept is given. The letter (S or D) at the beginning of the names given in the graphic indicates static or dynamic coating, while the number next indicates the coating speed (rpm). As can be clearly seen in Figure 3, the highest efficiency value was obtained with the dynamic coating technique at 800 rpm, while the lowest efficiency value was observed with the static coating at 2000 rpm (Table 1). In table 1, the last column shows the average values which are obtained from the arithmetic average of all fabricated devices.

Table 1. Characteristics of solar cells

Cell Description	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF	Vmp [mV]	Efficiency [%]	Average efficiency (%)
S800	7,52	550	0,42	350	2,15	2,00
D800	7,63	550	0,45	350	2,34	1,87
S1000	7,75	500	0,46	300	2,22	1,92
D1000	7,37	450	0,43	300	1,87	1,79
S2000	5,67	400	0,48	250	1,36	1,18
D2000	6,11	400	0,48	250	1.48	1,37

Considering the static and dynamic coating technique as a basis, different film formations can be obtained according to the viscosity of the solution. While the dynamic coating is expected to give a more uniform morphology in films with low viscosity, ripples are expected on the film surface in the opposite case. The better yields at low coating rates show that both the concentration and the viscosity of the active layer solution are good. On the other hand, another result that supports this situation is the reproducibility values in static and dynamic coatings at low speed. Although the dynamic coating gave the highest efficiency value at 800 rpm, it was observed that the static coating gave more reproducible results at 800 rpm in case reproducibility test results were considered and evaluated.

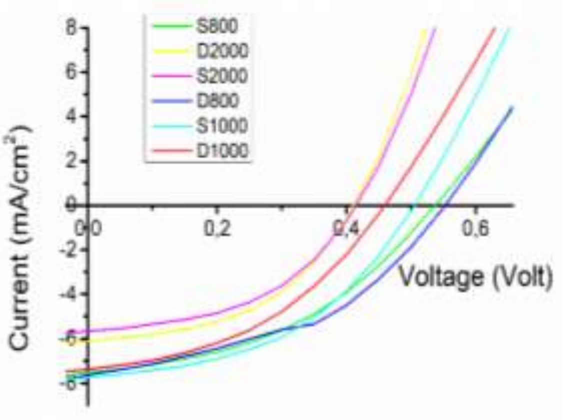

Figure 3. IV curves of solar cells

Looking at Figure 4 shows the reproducibility test results of all cell concepts. As it is known, one of the most critical parameters in solution-based thin-film device technologies such as organic solar cells, organic

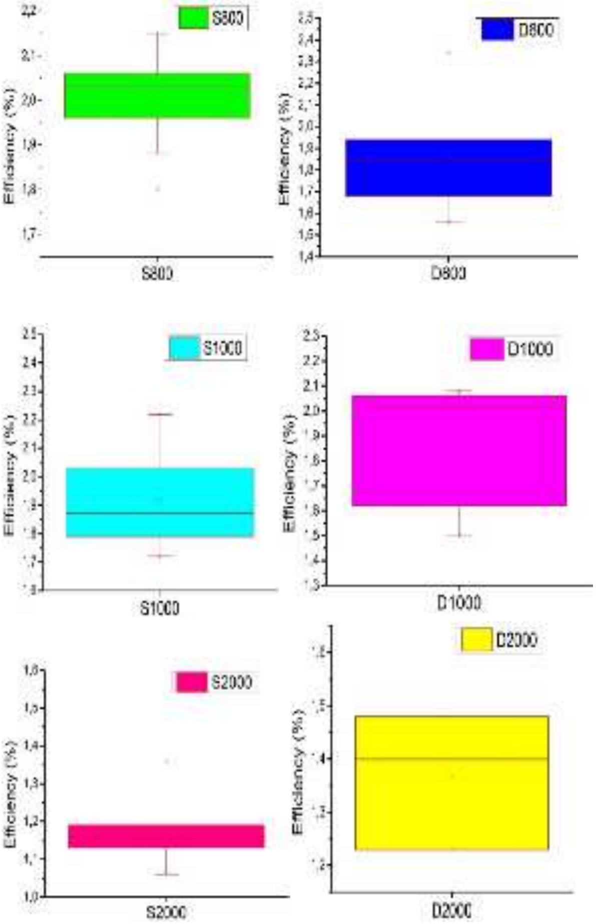

Figure 4. Reproducibility of solar cells.

4. Conclusion

As well-known, stability and reproducibility are critical parameters for organic solar cells. Many researchers focused to improve those parameters with different approaches. In this study, we focused on process optimization for coating parameters to achieve both high efficiency and reproducibility. As a result, using a mixture of chlorobenzene and dichlorobenzene as the solvent given in the experimental part, solvent concentration at the level of 2% and static coating at 800 rpm are the best parameters for reproducible and highly efficient solar cells.

Author's Contributions

Esma Yenel: Drafted and wrote the manuscript, performed the experiment and result analysis.

Ethics

There are no ethical issues after the publication of this manuscript.

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