Analysis of the degradation of high-efficiency encapsulated PM6:Y7-based Photovoltaic Cells

Análisis de la degradación de celdas fotovoltaicas encapsuladas de alta eficiencia basadas en PM6:Y7

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Degradation Analysis; PM6:Y7; organic solar cells; no fullerenes acceptor; encapsulated cells.

Abstract
In this work, we report a degradation study of high-efficiency conventional polymer solar cells (PSCs). The high performance of the PM6:Y7-based device is achieved with a power conversion efficiency (PCE) of up to 15.64% in the first measurement. The article describes the results of the measurements and analysis of the degradation process. The electrical parameters during the degradation process were extracted from the current density – voltage characteristics curves (J–V) under light and dark conditions. Were observed the specific parameters of the selected cells: open-circuit voltage ($V_{oc}$), short circuit current density ($J_{sc}$), fill factor (FF), PCE, series ($R_s$), and shunt ($R_{sh}$) resistance values. The PCE of the device decreased down to 64% of the initial PCE after 1056 h.

Introduction
Today's developments in organic solar cells allow us to look to the future of the field with hope. Polymer Solar Cells (PSCs) are attracting attention due to their light weight and low cost, as well as their ability to be manufactured on a large-scale using roll-to-roll technology. The materials used as the electron transport layer (ETL) and hole transport layer (HTL) play an important role in the electrical performance of the device [1-4]. In this text, we would like to present the results of research on conventional PSC fabricated were based on the structure of ITO/PEDOT:PSS/PM6:Y7/PDINO/Ag carried out during 1056 hours.

Materials and methods
Conventional PSC fabricated were based on the structure of ITO/PEDOT:PSS/PM6:Y7/PDINO/Ag as shown in Figure 1(a). Firstly, the ITO glass substrates were cleaned. Then the PEDOT:PSS solution was deposited on top of the precleaned ITO substrates at 4000 rpm for 40 s and then annealed in the air for 15 min at 150 °C. The active layer PM6:Y7 blend with the weight ratio of 1:1 was dissolved in chlorobenzene (CB) and 1-chloronaphthalene (CN), (CB:CN = 99.5:0.5
by volume). The blend solution was spin-coated onto the ITO/PEDOT:PSS substrates to obtain an active layer thickness of around 100 nm. Afterward, the electron transport layer, PDINO was deposited by spin coating at 3000 rpm for 30 s, obtaining a thickness of 35 nm. Then was evaporated at 100 nm Ag under high vacuum conditions. The effective area of the devices was 0.09 cm².

Figure 1. (a) Conventional architecture of the fabricated based in PM6:Y7. (b) Illuminated J-V curves over time under AM 1.5G spectrum.

Results

In this part of the work, we study to analyze the performance and the stability of PSCs. The current density-voltage (J-V) characteristics of the devices under light (Figure 1b) and dark (Figure 2b) were performed at room temperature using a Keithley 2400 source measure 100 mW/cm² and AM1.5G spectrum. The encapsulated devices were analyzed under an air environment for up to 1056 h. Figure 1(b) shows illumination the current density-voltage (J-V) characteristics curves under illumination condition and performance of the freshly prepared samples, GL1-T0, and after the photo-aging test: GL2-T48 (48 hours after the first measurement), GL3-T600, GL4-T864, up to GL5-T1056 (1056 hours after the first measurement). It can be observed that the J − V curve for the degraded cell under AM 1.5G illumination (Figure 1b) was shifted to lower open-circuit voltage (VOC) like as [5,6,9].

Moreover, Table I shows the specific parameters of the selected cells: open-circuit voltage (VOC), short circuit current density (JSC), fill factor (FF), power conversion efficiency (PCE), series (Rs), and shunt (Rsh) resistance values. Where the PCE, VOC, JSC, FF values were reduced from 14.2%, 820 mV, 28.6 mA/cm², 0.60 at T0, to 5.1%, 600 mV, 19.9 mA/cm², 0.42, at T1056. Figure 2(a) shows full graphs of all measurements for which selected data are shown in Table 1. The normalized performance parameters detailed that have been investigated over time until reaching T1056.
Table 1. Performance parameter for the fabricated PSC.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$V_{OC}$ (mV)</th>
<th>$J_{SC}$ (mA/cm$^2$)</th>
<th>FF</th>
<th>PCE (%)</th>
<th>$R_s$ (Ωcm$^2$)</th>
<th>$R_{sh}$ (Ωcm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh T0 h</td>
<td>820</td>
<td>28.6</td>
<td>0.60</td>
<td>14.2</td>
<td>1.77</td>
<td>324</td>
</tr>
<tr>
<td>T48 h</td>
<td>810</td>
<td>29.2</td>
<td>0.65</td>
<td>13.1</td>
<td>1.82</td>
<td>210</td>
</tr>
<tr>
<td>T600 h</td>
<td>780</td>
<td>25.4</td>
<td>0.53</td>
<td>10.5</td>
<td>2.65</td>
<td>203</td>
</tr>
<tr>
<td>T864 h</td>
<td>670</td>
<td>23.2</td>
<td>0.49</td>
<td>7.6</td>
<td>3.66</td>
<td>139</td>
</tr>
<tr>
<td>T1056 h</td>
<td>600</td>
<td>19.9</td>
<td>0.42</td>
<td>5.1</td>
<td>7.79</td>
<td>115</td>
</tr>
</tbody>
</table>

In Figure 2(a), the cells show a first, faster decay of PCE (approximately 7% of the starting value) in the initial hours from 0 h to 48 h. This atrophy is generally described as one of the degradation damage mechanisms, which is known as “burn-in loss”[7, 8]. Subsequently, in the case of PCE, we can observe a sudden increase and a renewed downward trend. Beyond 408 h we can then observe only decreasing trends. Other the performance parameter to be taken into account is FF, as shown in Figure 2(a). The normalized FF in solar-aged devices decreases rapidly by about 11% of the initial value up to 96 h. The value then returns to a value of 98% of the initial value and gradually decreases.

Figure 2. (a) Comparison of the normalized performance parameters ($V_{OC}$, $J_{SC}$, FF, and PCE) of the degradation over time of 1056 h. (b) J-V curves over time under dark.

Figure 2(b) shows the J-V characteristic curves produced under dark conditions. It is clear that there is a gradual small increase in leakage current. This agrees with the gradual decrease in shunt resistance (Table 1).

Conclusion
The stability of high efficiency conventional PSC based on bulk heterojunction PM6:Y7 can be investigated by analysis of the current density-voltage (J-V) characteristics. The encapsulated PM6:Y7 devices presents a fast decrease in the first hours that is known as “burn-in loss”. However, the PCE of the devices remained over 30% after 1056 h. Therefore, the solar cells PM6:Y7 based is a promising structure that could be use in the future to scaling up the PSC. To better understand the degradation behavior of the cells were measure with the impedance spectroscopy. Therefore, the next work is to continue with the analysis of this measurements.
Acknowledgment

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References


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Introduction

Photovoltaic Solar Cells (PSCs) are attracting attention due to their lightweight and low cost, as well as their ability to be manufactured on a large scale using roll-to-roll technology. The materials used as the electron transport layer (ETL) and hole transport layer (HTL) play an important role in the electrical performance of the device.

Materials and Methods

Conventional PSC structure of ITO/PEDOT:PSS/PM6:Y7/PDINO/Ag

1. ITO glass substrates were cleaned.
2. PEDOT:PSS solution was deposited on top of substrates at 4000 rpm for 40 s, annealed in the air for 15 min at 150 °C.
3. PM6:Y7 blend with the weight ratio of 1:1 was dissolved in chlorobenzene (CB) and 1-chloronaphthalene (CN). (CB:CN = 95:5.05 by volume).
4. The blend solution was spin-coated onto the ITO/PEDOT:PSS (10-100 nm).
5. PDINO was deposited by spin coating at 3000 rpm for 30 s (33 nm) and evaporated at 100 nm Ag under high vacuum conditions.
6. The effective area 0.09 cm².

Results and Discussion

<table>
<thead>
<tr>
<th>Sample</th>
<th>FF (%)</th>
<th>Voc (mV)</th>
<th>Jsc (mA/cm²)</th>
<th>PCE (%)</th>
<th>Rs (Om²)</th>
<th>Rsh (Om²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>10.3</td>
<td>620</td>
<td>28.4</td>
<td>14.2</td>
<td>1.77</td>
<td>324</td>
</tr>
<tr>
<td>4 h</td>
<td>10.4</td>
<td>610</td>
<td>28.2</td>
<td>14.5</td>
<td>1.82</td>
<td>290</td>
</tr>
<tr>
<td>74 h</td>
<td>780</td>
<td>25.4</td>
<td>0.25</td>
<td>10.5</td>
<td>2.65</td>
<td>203</td>
</tr>
<tr>
<td>154 h</td>
<td>670</td>
<td>23.2</td>
<td>0.49</td>
<td>7.6</td>
<td>5.65</td>
<td>139</td>
</tr>
<tr>
<td>T104 h</td>
<td>600</td>
<td>19.9</td>
<td>0.42</td>
<td>5.1</td>
<td>7.79</td>
<td>115</td>
</tr>
</tbody>
</table>

Fig. 1 Conventional architecture of the fabricated devices based on PM6:Y7.

Fig. 2 (a) Measured current-density–voltage (J–V) characteristics (b) under dark. Measured at room temperature using a Kipp and Zonen source-meter, 100 mW/cm², under standard environment and time 105 h.

Fig. 3 Comparison of the normalized performance parameters (Voc, Jsc, P), fill factor (FF), and efficiency of the degradation over time of 105 h.

Conclusions and Next Steps

- The stability of high efficiency conventional PSC based on bulk heterojunction PM6:Y7 can be investigated by analysis of the current density–voltage (J–V) characteristics.
- The encapsulated PM6:Y7 devices present a fast decrease in the first hours which is known as “burn-in loss”.
- PCE of the devices remained over 30% after 105 h.
- Is planning to better understand the degradation, implementation of measurements spectroscopy.

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Illustration 1. Presented Poster at LAEDC 2022.