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

Patrycja Królak[1], Magaly Ramírez-Como[2], Josep Pallarès-Marzal[3], Lluis F. Marsal-Garví[4]

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1 Faculty of Civil Engineering, Architecture, and Environmental Engineering. Lodz University of Technology. Polonia. Email: 196246@edu.p.lodz.pl
https://orcid.org/0000-0002-3536-765X
2 Department of Electric, Electronic and Automatic Control. Universitat Rovira I Virgili. España. Email: magaly.ramirez@urv.cat
https://orcid.org/0000-0002-9313-8337
3 Department of Electric, Electronic and Automatic Control. Universitat Rovira I Virgili. España. Email: josep.pallares@urv.cat
https://orcid.org/0000-0001-7221-5383
4 Department of Electric, Electronic and Automatic Control. Universitat Rovira I Virgili. España. Email: lluis.marsal@urv.cat
https://orcid.org/0000-0002-5976-1408

Keywords

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.

Resumen

En este trabajo, nosotros reportamos un estudio de celdas solares poliméricas (PSCs) convencionales de alta eficiencia. El alto desempeño del dispositivo basado en PM6:Y7 se logró con una eficiencia de conversión de potencia (PCE) de hasta el 15.64 % en la primera medición. El artículo describe los resultados de las mediciones y el análisis del proceso de degradación. Los parámetros eléctricos durante el proceso de degradación fueron extraídos de las curvas características de densidad de corriente-voltaje (J–V) en condiciones de luz y bajo oscuridad. Se observaron los parámetros específicos de las celdas seleccionadas: voltaje de circuito abierto (V_{OC}), densidad de corriente de cortocircuito (J_{SC}), factor de llenado (FF), PCE, serie (R_S) y resistencia en paralelo (R_{SH}). La PCE del dispositivo disminuyó hasta el 64% del su PCE inicial después de 1056 h.

Palabras clave

Análisis de degradación; PM6:Y7; celdas solares orgánicas; aceptores no fulerenos; celdas encapsuladas.

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-chloronapthalene (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 cm^2.

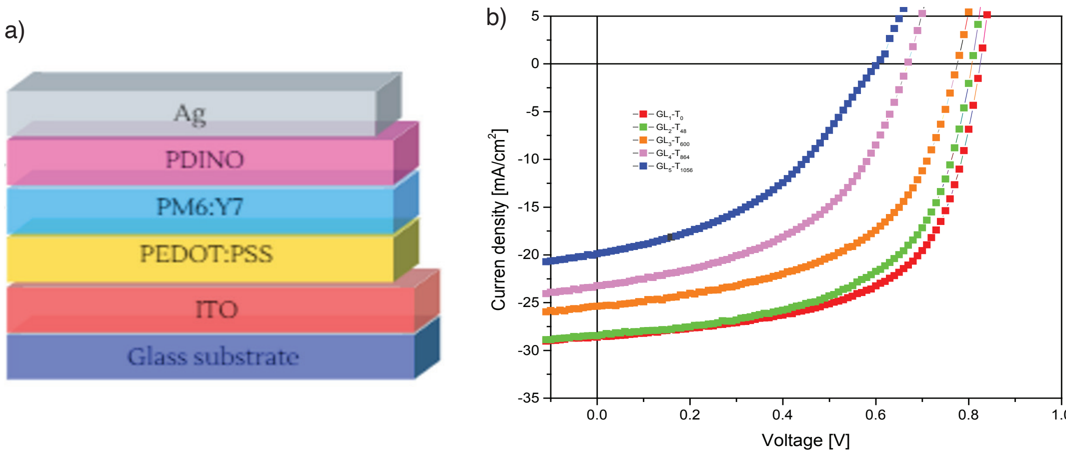

Figure 1. (a) Conventional architecture of the fabricated based in PM6:Y7.
(b) Illuminated J–V curves over time under AM 1.5G spectrum.

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/cm^2 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 (V_{OC}) like as [5,6,9].

Moreover, Table I shows the specific parameters of the selected cells: open-circuit voltage (V_{OC}), short circuit current density (J_{SC}), fill factor (FF), power conversion efficiency (PCE), series (R_S), and shunt (R_{SH}) resistance values. Where the PCE, V_{OC}, J_{SC}, FF values were reduced from 14.2%, 820mV, 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.

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

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.

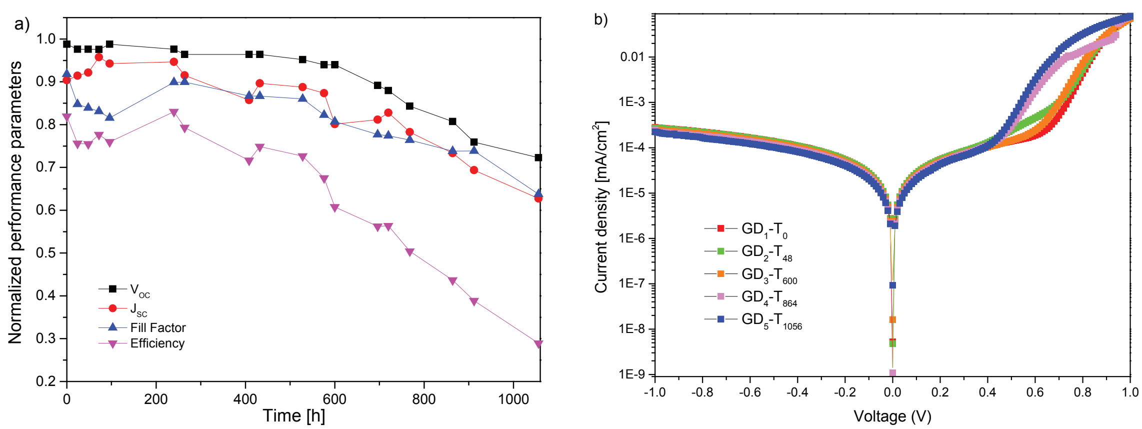

Figure 2. (a) Comparison of the normalized performance parameters (V_{OC}, J_{SC}, FF, and PCE) of the degradation over time of 1056 h. (b) J-V curves over time under dark.

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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Patrycja Królak[1], Magaly Ramírez-Como[2], Enas Moustafa[2], Alfonsina Abat Amelenan Torimtubun[2], Lluis F. Marsal[2], Josep Pallarès[2]
1 Faculty of Civil Engineering, Architecture, and Environmental Engineering, Lodz University of Technology, 93590 Lodz, Poland
2 Department of Electrical Electronic Engineering and Automatic, Universitat Rovira i Virgili, 43007 Tarragona, Spain
CORRESPONDING AUTHOR: Josep Pallarès (e-mail: josep.pallares@urv.cat)

Introduction

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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-chloronapthalene (CN), (CB:CN = 99.5:0.5 by volume).
4. The blend solution was spin-coated onto the ITO/PEDOT:PSS (+/-100 nm).
5. PDINO was deposited by spin coating at 3000 rpm for 30 s (35 nm) and evaporated at 100 nm Ag under high vacuum conditions.
6. The effective area 0.09 cm².

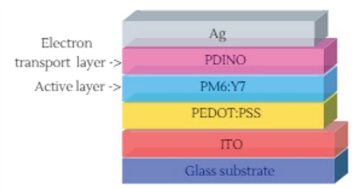

Fig. 1 Conventional architecture of the fabricated based in PM6:Y7.

Results and Discussion

Table I the specific parameters of the selected cells: open-circuit voltage (V_{OC}), short circuit current density (J_{SC}), fill factor (FF), power conversion efficiency (PCE), series (R_S), and shunt (R_{SH}) resistance values.

Sample	V_{OC} (mV)	J_{SC} (mA/cm²)	FF	PCE (%)	R_S (Ωcm²)	R_{SH} (Ωcm²)
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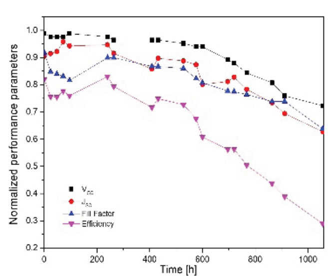

Fig. 2 Comparison of the normalized performance parameters (V_{OC}, J_{SC}, Fill Factor and Efficiency) of the degradation over time of 1056 h.

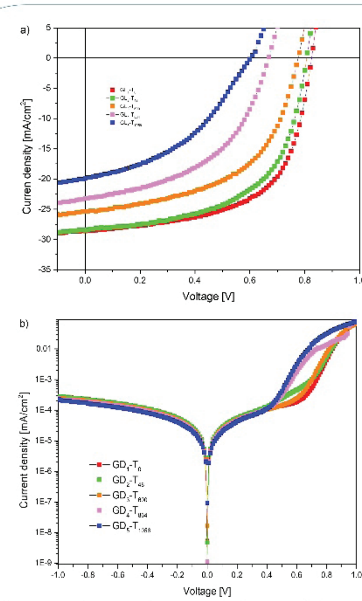

Fig. 3 (a) Illuminated density-voltage (J-V) characteristics **(b)** under dark. Were performed at room temperature using a Keithley 2400 source measuring 100 mW/cm², under an air environment and time 1056 h.

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 1056 h.
- Is planning, to better understand the degradation, implementation of measurements spectroscopy.

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Illustration 1. Presented Poster at LAEDC 2022.