Analysis of the stability of organic photovoltaic cells under indoor illumination

Análisis de la estabilidad de celdas fotovoltaicas orgánicas bajo iluminación interior

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Keywords

Degradation Analysis; encapsulated solar cells; current density-voltage; organic solar cells; PTB7:PC70BM; indoor illumination.

Abstract

In this study, we analyze the degradation behavior of conventional polymeric solar cells (PSCs) under constant indoor light illumination. A LED lamp with a color temperature of 2700 K, was used for the indoor light illumination conditions. We compare the results obtained with encapsulated and non-encapsulated devices. The performance of the PTB7:PC_{70}BM-based cell showed an initial maximum power conversion efficiency (PCE) of 12.0% under the luminance of 1000 lux and maximum power density (MPP) of 45.7 μW/cm^2. The work describes the results of the measurements and analysis of the degradation process, performed by a current density – voltage (J–V) characteristic curve study under LED light. The analyzed performance parameters were PCE, short circuit current density (J_{SC}), open-circuit voltage (V_{OC}) and fill factor (FF). The PCE of encapsulated devices remained above 80% of the initial value after 624 h.

Palabras clave

Análisis de degradación; celdas solares encapsuladas; densidad de corriente-voltaje; celdas solares orgánicas; PTB7:PC70BM; iluminación interior.

Resumen

En este estudio, nosotros analizamos el comportamiento de degradación de celdas solares poliméricas convencionales (PSCs) bajo iluminación de luz interior constante. Para las condiciones de iluminación de luz interior se utilizó una lampara LED con una temperatura de color de 2700 K. Nosotros comparamos los resultados obtenidos con dispositivos encapsulados y no encapsulados. El desempeño de las celdas basadas en PTB7:PC_{70}BM muestra una eficiencia de conversión de potencia máxima (PCE) inicial de 12.0% bajo la iluminancia de 100 lux y una densidad de potencia máxima de 45.7 μW/cm^2. El trabajo describe los resultados de las mediciones y el análisis del proceso de degradación realizado mediante el estudio de la curva característica densidad de corriente – voltaje (J-V) bajo iluminación LED. Los parámetros de desempeño analizados fueron la PCE, la densidad de corriente de corto circuito (J_{SC}), el voltaje de circuito abierto (V_{OC}) y el factor de llenado (FF). La PCE de los dispositivos encapsulados permaneció por arriba del 80% de su valor inicial después de 624 h.

Introduction

Research in fields related to energy generation has been prominent for decades now because of fossil fuels being scarce and for having a negative impact on the environment, becoming one of the main causes of global warming and air pollution [1] [2]. The interest in finding clean and inexhaustible alternatives has led to the study of different natural resources, like solar energy [3]. However, there are many aspects that need to be investigated for further development, including looking for organic materials capable of substituting silicon as the main active material in photovoltaic cells. One example are semiconducting organic polymers [1], which have advantages like being cheaper, easier to prepare, flexible and lightweight [4].

The problem right now is that organic materials can't display efficiencies comparable to silicon-based cells, and their degradation rates are not satisfying. However, something about organic cells that has attracted the attention of researches lately is their potential for indoor applications.

In recent years the amount of electronic devices has increased exponentially, especially those related to communications that conform the Internet of Things (IoT) [5]. This has motivated the investigation of ways to charge them without relying on batteries [6]. As a result, photovoltaic cells have become interesting for this purpose, seeing that electronic devices like IoT usually demand electrical power in ranges of 1 to 100 mW. This is something possible using solar cells and has directed researchers to new areas of development [7].

The reason why organic solar cells (OSC) are especially interesting for indoor applications is that organic materials have the ability to absorb radiance in the visible region of the light spectrum, ranging from 390 to 760 nm. This matches common artificial light used at offices and areas of very high visual demand, like LEDs [8], which require illuminations of at least 500 or 1000 lux [9]. Studies have proven to really promising, as the use of certain organic materials has led to PCE of over 23% under a 1000 lux LED [10].

Even after those positive results, the stability of the devices is still an unsatisfactory key aspect that stops their possibilities to be commercialized [11]. Encapsulation becomes an especially interesting process to achieve long-term performances by providing protection from external threats, turning into a direct link to the device's stability [12]. In addition, external and internal factors that affect degradation need to be studied to understand the process that takes place at each one of the device's layers [13] [14].

In this project, the evolution of J-V parameters is performed to understand the degradation of conventional polymeric cells, using a copolymer called PTB7:PC_{70}BM as the active layer. Similar materials or structures have been studied in previous works, achieving promising results [15, 16] and making it interesting to investigate other variations. The behavior of the cells is studied under 1000 lux artificial LED 2700 K light, following the consensus stability testing protocols for organic photovoltaic materials and devices [17]. The encapsulated and non-encapsulated cells are kept under controlled environments to see how this affects degradation.

Materials and methods

The conventional structure chosen for this project was the next one: ITO/PEDOT:PSS/ PTB7:PC_{70}BM/Ca/Ag. To start the fabrication of the 0.09 cm^2 cell, the ITO-patterned glass substrates were carefully cleaned to remove any possible dust or residue. The deposition of the first layer, PEDOT:PSS, was by spin coating at 4000 rpm for 40 s. After that, the samples were put in a heating plate for 15 min at 150 °C for thermal annealing. The rest of the process was performed inside a glove box under nitrogen environment. The active layer solution was prepared in advance, as it needs to age for 48 hours before spin coating it for 30 s at 750 rpm to get a 100 nm width layer. The next two layers, 25 nm of Ca and 100 nm of Ag, were added applying a thermal evaporation procedure inside a vacuum chamber under high pressure conditions.

Results

Two structures of cells were studied, Figure 1 shows the current density-voltage (J-V) characteristics curves under LED illumination condition of the fabricated OSCs. The encapsulated device displaying an initial power conversion efficiency of 12.0%, which decreased to 9.5% after 625 h. This contrasts with the results obtained with cells stored in air, which started at 9.3% and got to 3.5%.

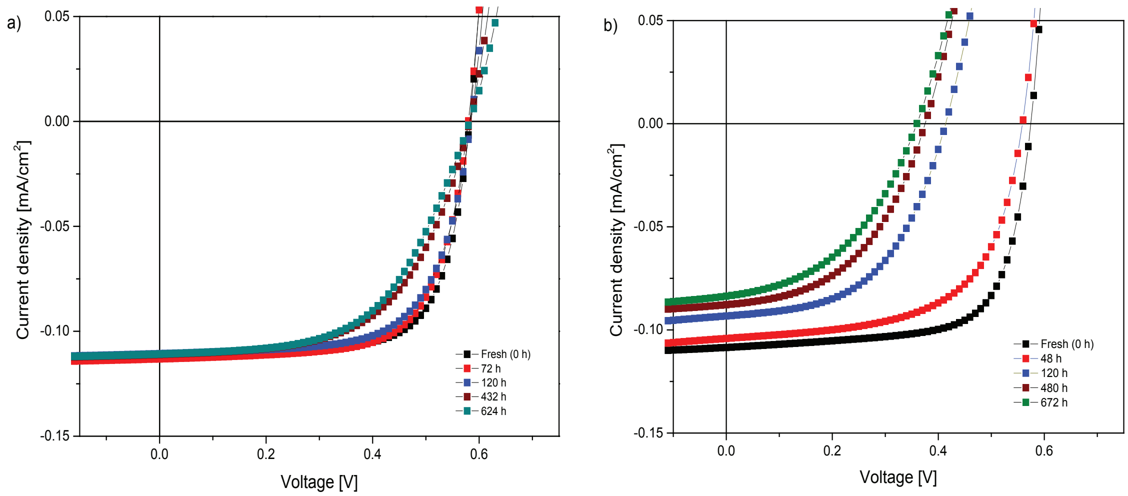

Figure 1. Illuminated J–V curves over time under LED spectrum of OSC based in PTB7:PC70BM a) encapsulated devices, b) non-encapsulated devices.

In addition, the performance parameters (V_{OC}, J_{SC}, PCE, FF) that were obtained from the J–V characterization were normalized with respect to the initial values (Figure 2). This normalization displays how these values drastically decrease in the air stored cells, in which efficiency goes down in a 55% during the first 100 h, getting to lose 70% in about 500 hours. On the other hand, both V_{OC} and FF go down in a 25%, decreasing until the 60% at 500 hours. J_{SC} is the parameter with less changes, decreasing first 15% and then staying mostly stable, ending in the 80%. In contrast, encapsulated cells only see a gradual decrease in FF and PCE parameters, getting down to an 80% after 600 hours, while V_{OC} and J_{SC} stay mostly stable, barely losing a 5% of its initial values. This confirms the positive consequences of applying an encapsulation thanks to the protection of the cells from extrinsic factors like oxygen, and water [14]. While that, the non-encapsulated cells were faster degraded because of being affected by both extrinsic and intrinsic factors which easily degrade organic cells' active layer. Research have concluded that their main degradation cause is UV irradiation because it alters both carrier mobility and the recombination process that creates current, leading to the decrease of PCE between other characteristic parameters [18].

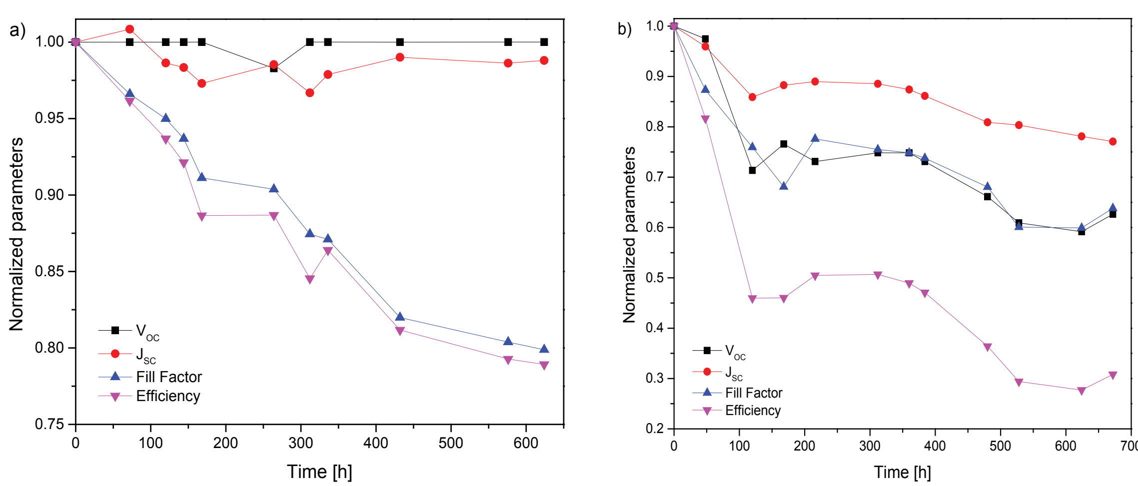

Figure 2. Comparison of the normalized performance parameters (V_{OC}, J_{SC}, FF and PCE) of the OSC during the degradation over time of 650 h a) encapsulated devices, b) non-encapsulated devices.

Conclusion

A first study on the degradation of conventional polymer:fullerene OSC based on PTB7:$PC_{70}BM$ can be performed thanks to the analysis of J-V characteristics. During the first 150 h there is a fast decrease in several parameters, which is known as "burn-in loss". This can be seen during the first 100 h, especially in the non-encapsulated devices, after which there is a slower degradation. The biggest difference is in PCE, decreasing a 70% in non-encapsulated devices after almost 700 h, while encapsulated ones only dropped around a 20%, confirming the importance of applying encapsulation to OSC to achieve better stability

Acknowledgment

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Analyzing the Stability of Organic Photovoltaic under Indoor illumination

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Introduction

Research related to energy generation has been prominent for decades now, leading to the study of clean and inexhaustible sources like solar energy. This field has many possibilities, including the use of semiconducting organic polymers instead of silicon as active materials.

In addition, the use of organic materials has big potential for indoor applications thanks to their ability to absorb radiance in the visible region of light spectrum, matching common artificial light. However, these cells don't have good enough efficiencies, stability and degradation rates.

Encapsulation becomes an important process to achieve long-term performance, providing protection from external threats.

Behavior analysis.
Evolution of J-V parameters to understand cell's degradation.
Analysis under 1000 lux artificial LED 2700 K light.

Materials and Methods

Preparation of conventional PTB7: $PC_{70}BM$ polymer cells.

ITO/PEDOT:PSS/PTB7:$PC_{70}BM$/Ca/Ag - 0.09 cm^2

1) Polymer solution preparation - Aging for 48 h.
2) Clean ITO-patterned glass substrates.
3) PEDOT:PSS deposition (spin coating at 4000 rpm for 40 s).
4) Annealing at a heating plate for 15 min at 150 °C.
5) PTB7:$PC_{70}BM$ deposition (spin coating for 30 s at 750 rpm).
6) Ca deposition (thermal evaporation under high pressure).
7) Ag deposition (thermal evaporation under high pressure).
8) Optical Adhesive encapsulation.

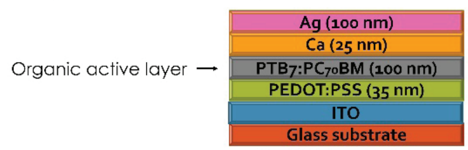

Fig. 1 Cell's structure.

Results and Discussion

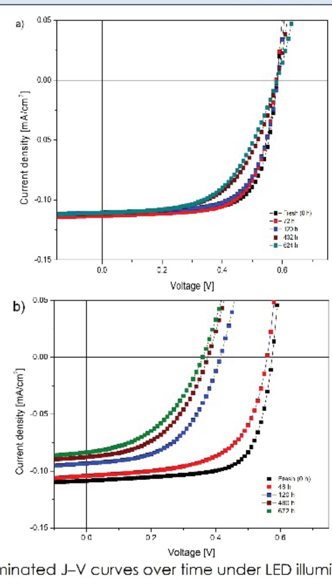

Fig. 2 . Illuminated J–V curves over time under LED illumination a) encapsulated cells, b) non-encapsulated cells.

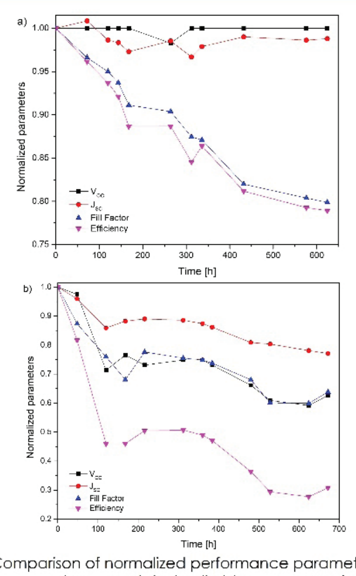

Fig. 3 . Comparison of normalized performance parameters over 650 h a) encapsulated cells, b) non-encapsulated cells.

Conclusions

- During the first 150 h there is a fast decrease in several parameters, which is known as "burn-in loss".
  Burn-in losses appear especially during the first 100 h in non-encapsulated devices.
- The biggest difference is in PCE.
  Decreases a 70% in non-encapsulated devices after almost 700 h, while encapsulated cells remained close to 80%.
- In encapsulated cells the fill factor decreases in a similar way to the efficiency, while Voc and Jsc barely change.
- In non-encapsulated cells fill factor and Voc both decrease in a similar manner, ending at a 70% while Jsc stays at 80%.
- **Confirmation of the importance of OSC's encapsulation to achieve better stability.**

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Illustration 1. Presented Poster at LAEDC 2022.