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Study of charge carriers' transport in organic solar cells by illumination area shifting

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ABSTRACT

This paper presents an original investigation method to highlight the differences of mobilities and transport mechanisms of charge carriers in organic materials solar cells.

Two types of polymer: fullerene solar cells were investigated: ITO/ PEDOT:PSS/P3HT:PCBM /Al and ITO/ PEDOT:PSS/PCDTBT:PCBM/Al. The I–V characteristics were done under standard illumination (1000 W/m^2) using a mask placed at different distances from the collecting cathode position. The influence of the distance between the irradiation area and the position of the collecting electrode on the performances of solar cells was studied. It has been observed that the short-circuit current and the open-circuit voltage considerably increase with the decrease of the distance between the cathode and the irradiation area.

This study method gives also the opportunity to find the suitable collecting grid layout (distance between electrodes) depending on the nature of the organic materials. Moreover it can also explain the differences observed between the reported values in literature for the conversion efficiencies of organic solar cells.

1. Introduction

The new achievements in organic solar cells research conducted to very promising results with a current efficiency record of 11.1% [1]. However we can notice a high diversity between the values of conversion efficiency obtained in different laboratories [2]. Many factors conduct to this dispersion of the results such as: the quality of the transparent electrodes [3–8], the presence or not of different buffer layers [9–11], the layout and size of the electrodes [12–15], the preparation conditions [16–20] the devices stability [21–23] etc. Many studies emphasise that higher efficiencies are obtained for solar cells of smaller sizes [9,13,14,24]. However, the progress in organic and hybrid photovoltaic gives the opportunity to move rapidly towards commercialization and large scale manufacturing. To this end, a suitable optimized design for the electrode grids has to be found.

To obtain good efficiencies, it is necessary to avoid collisions and charge recombinations. To this aim, a good repartition of the collecting areas of photo-generated carriers is essential.

In this paper we propose a new method to investigate the transport mechanisms in different organic materials and the differences on charges mobilities of the photo-generated carriers, in order to choose the suitable collecting grid layout, depending on the organic materials nature. The short circuit current density (J_{sc}) and the open-circuit-voltage (V_{oc}) are measured at different distances between the top ITO electrode and bottom Aluminum collecting cathode by illumination area shifting. The slope of the curves depends on the active material nature, and the distance for which the $J_{sc,}$ V_{oc} reach the minimum value, indicates the maximum distance at which the bottom Aluminum electrode should be placed.

This study is especially important to optimize the efficiency of solar cells panels. In the case of solar cells panels, the whole panel area is irradiated and the efficacy of the panel is calculated without limiting the irradiation area to the collecting electrode surface area. An optimized distance between the collecting electrodes will conduct to an optimized harvesting of photo-generated charge and hence to an increased efficiency.

The experimental values obtained in this study were correlated with the numerical simulations' results, using the **F**inite **E**lements **M**ethod (FEM).

2. Experimental details

ITO coated glass substrates, purchased from Ossila, were cleaned with ethanol followed by multiple rinsing in de-ionized water and then dried at 120 °C for one hour inside an oven.

PEDOT:PSS films were subsequently deposited by spin coating at

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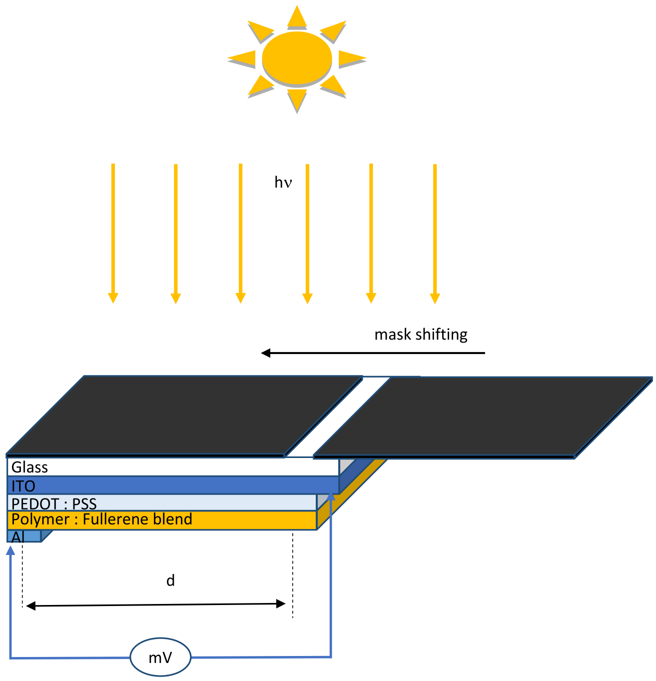

Fig. 1. Experimental set-up.

velocities comprised between 1000 RPM and 1500 RPM. P3HT highly regioregular (> 98%) poly(3-hexylthiophene-2,5-diyl) purchased from Rieke Metals, PCDTBT - Poly[N-9′-heptadecanyl-2,7-carbazole-*alt*-5,5-(4′,7′-di-2-thienyl-2′,1′,3′-benzothiadiazole)] purchased from Ossila and PCBM - Methanofullerene Phenyl-C_{61}-Butyric-Acid-Methyl-Ester purchased from SES research were used for the preparation of active layers.

P3HT:PCBM films (1:0.8 wt%) and PCDTBT:PCBM films (1:4 wt%) were spin coated from chlorobenzene solutions on ITO electrodes using spinner speeds between 400 RPM and 450 RPM. After spin-coating, the samples were dried in oven for 20 min at 110 °C.

Finally 60 nm of Aluminum were evaporated as cathode through a proper shadow mask defining an area of 0.04 cm^2. Our device configuration is depicted in Fig. 1.

Obtained cells were studied as prepared, without annealing, the aim to this work not being the improvement of the efficiency by different treatments, but the understanding of the impact of the irradiation/ cathode distance on solar cells performance.

Current–voltage (J–V) characteristics in the dark and under illumination were measured using a Keithley 2400 source measurement unit. For cell characterization during illumination, a 1000 W/m^2 white light from an AM 1.5 solar simulator was used. The devices were illuminated through the ITO transparent electrode, serving as an anode in our device structure.

The devices numerical simulation were performed using COMSOL software.

3. Results and discussions

The higher efficiencies, reported in literature for smaller size organic solar cells, can be explained in some cases by calculus reasons. In some reports this is due to the fact that surface of the irradiated area is generally larger than the cathode area. Indeed the calculus of the conversion efficiency is given by:

$$\eta = FF\frac{V_{oc}\frac{I_{sc}}{S}}{\Phi} \quad (1)$$

where, V_{oc} is the open circuit voltage, I_{sc} the short circuit current, Φ=1000 W/m^2 the standard solar irradiation power by square meter, S the solar cell surface and FF the fill factor.

The photo-generated current depends on the area (S′) of the irradiated surface. The more S′ increases, the more the short circuit current I_{sc} increases.

When the I-V characteristics are done using a mask which corresponds to the position and the size of the back metallic electrode, the defined area of the cell coincides with the size of the electrode S=S′ (Fig. 2.a). If the I-V characteristics are done without a mask and if in Eq. (1) the surface S is considered to be the surface of the electrode, the smaller the electrode is the greater the efficiency seems (Fig. 2b).

For solar panels, the I-V characteristics are done without mask and in Eq.1, the surface S is considered to be the whole irradiated surface area and most times, the reported efficiencies are smaller than for individual solar cells (Fig. 2.c). The collection of the photo-generated carriers by the central electrode is shared with the two adjacent electrodes. The number of photo-generated carriers collected by one electrode (excepting edges electrodes) corresponds to the area S′=(d_e /2+w_e+d_e /2)×L, where d_e is the distance between electrodes, w_e the width of the electrode and L the length of the electrode. Consequently the efficiency of solar panels will depend on the dimensions of the electrodes and distance between them.

In other cases, when masks are used, this higher efficiencies values are attributed to lower series resistances of the ITO front electrode. Generally there is an important lack of information on the details of the geometries, surfaces of the collecting grid electrodes and on the way efficiencies are calculated.

Hence, besides the different preparation factors, these differences of the grid electrodes layout and calculations methods can also explain the dispersion of the values reported in literature for OPV solar cells efficiencies.

In this study the short circuit current density and the open circuit-voltage were measured for different distances between the illuminated area and the collecting cathode position for the two kind of solar cells: ITO/PEDOT:PSS/P3HT:PCBM/Al and ITO/ PEDOT:PSS/PCDTBT:PCBM/Al by mask position shifting. A high dependence of the characteristic parameters of solar cells: J_{sc}, V_{oc} and FF (Fill Factor) on the mask position was remarked.

The normalized values of the photo-generated current at different distances are shown in Fig. 3. The photo-generated charge carriers are located in the area of the illumination zone and these charge carriers can be easily taken away thanks to the nearby electrode. As a result of this, the photo-current, which removes the photo-generated carriers from the generation zone, travels from the active layer zone to the electrodes. The nature of the active layer and series resistance of the electrodes is important because it influences the transport mechanism through the device. Charge carriers diffuse along the diode bulk through the electrodes and a part of them recombine.

Consequently, the slopes of these curves can be related to the electrons mobility and can indicate the optimal distance between electrodes in order to avoid the losses by recombination.

The normalized values of the open circuit voltages are plotted in Fig. 4. The open circuit voltage is much higher in the center, at d=0 (where the electrode is vertically located under the illuminated area), than at the edge. This can be explained by the fact that the voltage value is proportional to the number of collected photo-generated charge carriers.

Because the charge carriers' path is shorter in the center (same vertical position) the losses by recombination are smaller and hence the photo-generated current and open circuit voltage are higher in the center compared to the edge.

Fig. 5 shows the normalized values of the fill factor (FF/FF_{max}). The smaller values of the fill factor when the vertical position of the illuminated area coincides with the cathode position (d=0) can be understood by the fact that a high number of carriers are photogenerated, but their harvesting mechanism is not fast enough, hence their collection is not efficient because of the increased number of collisions.