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Experimental investigation of tensile mechanical strain influence on the dark current of organic solar cells

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A R T I C L E I N F O

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A B S T R A C T

In this paper we have experimentally studied the electrical behavior of organic solar cells (OSCs) under mechanical strain in dark condition. Dark current-voltage characteristics of solar cells provide valuable information on the defect states inside the device. The samples under tests here are two commercial polymeric solar cells with different electrode types. So, instead of studying merely the dark current changes of the solar cells versus strain, the electrodes effects due to the applied strain are compared at different environment temperatures. The most important electrical parameters of the strained cells are extracted as a function of the strain at different temperatures for two conditions: when the cells are under strain and when they are relaxed for 3 min after applying the strain. The only parameter that shows a considerable meaningful change by strain is the series resistance. The final results confirm that the cell with silver electrodes, shows a current increase by tensile strain due to the polymeric chains alignment along the strain direction. But the cell with carbon electrodes experiences a current decrement by increasing the strain. We believe that the carbon electrode, due to the larger carbon Young's modulus, in comparison with the silver electrode cells creates more defect states in the flexible polymeric cells under the same amount of the applied strain. Furthermore, the cell with softer and more stretchable silver grid electrodes can withstand a higher level of strain before suffering any permanent damage.

1. Introduction

Organic Solar Cells (OSCs) are not vastly used for commercial purposes yet. However, due to their advantages, especially low-cost manufacturing process, they are currently a hot-topic of analytical and experimental investigations [1–5]. An important feature of organic devices is the mechanical flexibility which makes them greatly useful for some special applications including flexible displays, electronic newspapers, wearable electronics, biotechnology and so on [6–11]. It is obvious that any change in the physical shape of the material will affect its electrical behavior and these effects have to be measured and restricted to certain amounts that would not disturb the correct functioning of the device. So a lot of efforts are performed lately to investigate the effects of the mechanical deformations on electronic devices such as Organic Thin Film Transistors (OTFTs) [12,13]. Solar cells have also been under focus and some researchers have investigated different solar cells accordingly, an example of which is the tests done on the silicon solar cells [14,15]. The OSCs' behavior is examined mostly for the induced mechanical strain during the fabrication [16–19]. Also, some works have been done to understand this phenomenon in the finished OSCs [20–23]. However, more researches are still needed to be done in order to study the different aspects of the strain effects on electrical behavior of the currently available commercial OSCs for their proper applications.

It is already known that the electrode plays an important role in the device electrical behavior under strain, even the electrode can be the most determinant layer in the cell in this aspect. Indium Tin Oxide (ITO) is a common transparent electrode material widely used in the bulk heterojunction OSCs. Ryu and Loh used OSCs as strain sensors. Although, in their experiments, they showed that the tensile strain improves the active layer's conductivity and the solar cell exhibits a photo current proportional to the applied strain, brittleness of the ITO electrode used was a major problem during the tests and it greatly reduced the strain sensor dynamic range [20]. In order to improve their sensor, Ryu et al. used the inkjet printed poly (3-hexylthiophene)–based OSCs. They showed that the more flexible PEDOT:PSS electrode did not suffer from this problem and it showed an almost negligible change in its resistivity under the tensile strain [21]. In addition, some replacements have been recently considered to be used as electrodes in the OSCs for some reasons including the cost and rarity of the ITO [24–27].

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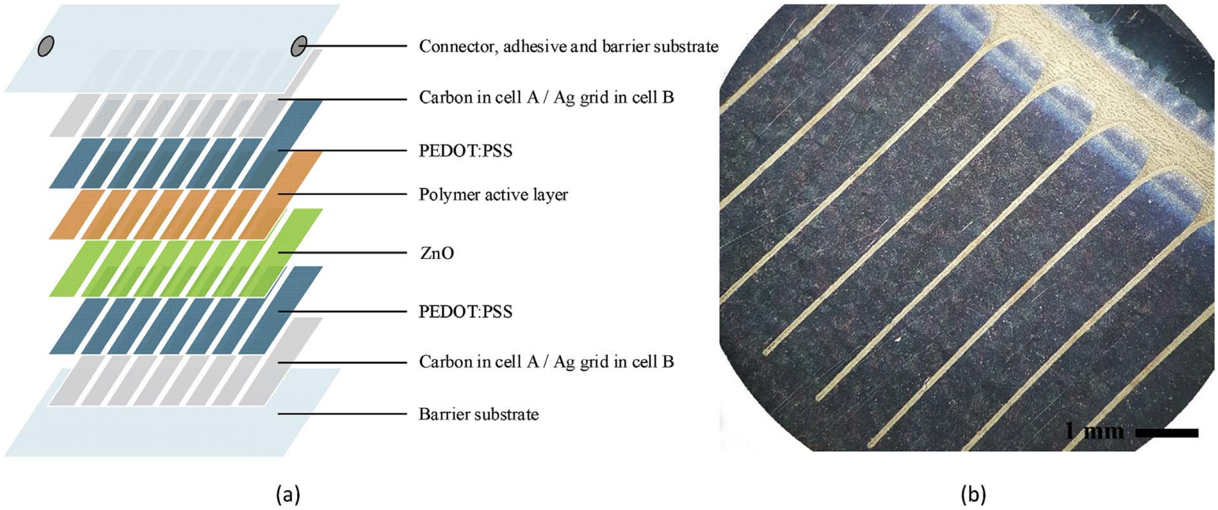

Fig. 1. (a) Constructing layers of the cells under test. Cell A has Carbon electrodes while in cell B electrodes are made of Ag grid [28] (b) Photo of the comb shaped Ag grid electrode of cell B.

Thus, in this work following the trail of the preceding researches, the electrodes role in the electrical behavior of the strained OSCs is particularly investigated. Here, two different commercial OSCs with two different types of electrodes are strained and their electrical parameters are compared. These cells will be referred to by solar cells A and B in this paper. While the cell A is a metal-free device and its electrodes are made of PEDOT:PSS and a carbon layer, the solar cell B has PEDOT:PSS electrodes with a layer of silver grid as shown in Fig. 1 [28,29]. The cells under study have different active layers but this difference, as it will be explained later in section 3, is considered to be ignorable here. Comparing the results of these two cells with the results achieved by previous researches gives an enlightening view about the importance of the electrodes when the solar cell is under the tensile strain. It is noteworthy that the tests are done in dark condition and the information achieved can provide an insight into the defect states in the cells.

2. Experimental

In order to study the OSCs under the mechanical tensile strain, we designed a metal structure which makes it possible to apply a uniformly distributed strain along the cell under test, as shown in Fig. 2. The test structure consists of two metal holders that hold the solar cell firmly from both sides and two axles to fix the distance between them. In each state the distance between the two sides of the structure is accurately measured to determine the applied strain.

The solar cells are strained in several steps using the test structure explained above. The test sequence is as follows: after each strain step, we wait for 3 min so that the cell's morphology reaches to a stable condition; then, we measure the I-V characteristics using a Keithley 2400 source meter in a completely dark environment. Next, we release the cell to reach to its initial length and after another 3-minute-pause, we measure the I-V curve. This procedure is repeated in the following measurement step but the strain level increases by 480 με until any deformation of the cell is observed.

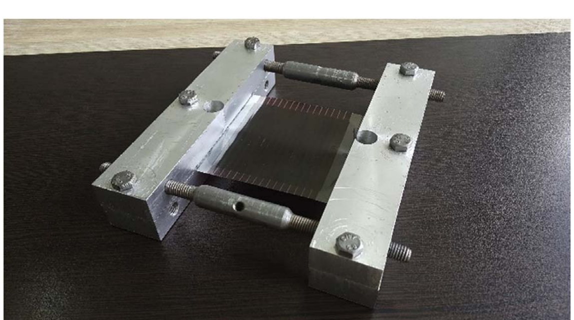

Fig. 2. The test structure used for straining the solar cells.

In order to have a better insight of the solar cell's changes, we extract the most important electrical parameters of the cell under test using Werner method [30]. In this method, different parameters of the cell can be achieved with the help of a single dark I-V curve. Considering its series and shunt resistances, the cell current will have a voltage dependence as

$$I = I_s\left(exp\left(\frac{\beta}{\eta}(V - IR_s)\right) - 1\right) + G_p(V - IR_s) \tag{1}$$

in which I_s is the saturation current, $\beta = e/KT$ is the inverse thermal voltage, η is the ideality factor, R_s is the series resistance and G_p is the shunt conductance. We extract R_s, $R_p = 1/G_p$, I_s and η of the cell under test for each test step.

3. Results and discussion

As can be seen in Fig. 3, although we cannot find any meaningful changes in R_p, I_s and η of the cells under test, significant variations in the series resistances are observed by increasing the applied tensile strain. The R_s values of cells A and B versus different levels of applied tensile strain and their corresponding second degree interpolated curves are shown in Fig. 4. As it is shown, the strain effects on the series

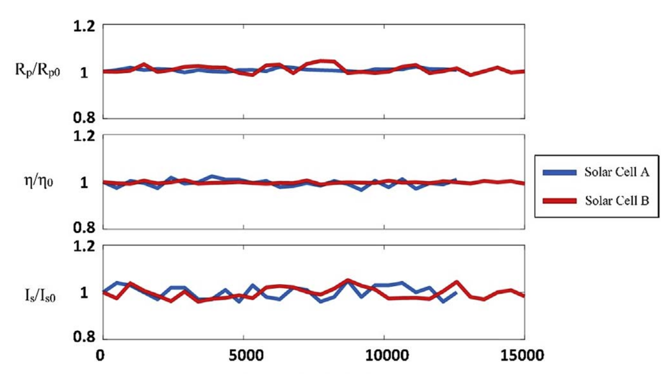

Fig. 3. Changes of the solar cells' electrical parameters with the tensile strain.