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Irradiance intensity dependence of the lumped parameters of the three-diodes model for organic solar cells

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ABSTRACT

In this paper the current-voltage characteristics of organic solar cells (OSC) is analyzed in terms of equivalent lumped parameter circuit at different level of insolation. In particular, starting from a circuital model based on a three-diode configuration, a set of formulas is proposed to describe the dependence of lumped circuital parameters on irradiance intensity and consequently the behaviour of organic solar cells from dark to high irradiance conditions. These expressions are achieved by using a trail and error approach applied to the fitting procedure of measured I-V curves at different irradiance levels. The achieved model with parameters dependent on irradiance level allows us to use a single circuit for the analysis of OSC under different operating conditions: this is the first step for the integration of OSC circuital model in photovoltaic system simulator, but also can furnish a novel point of view for the advance of the OSC applied research. Experimental measurements are used to setup the model and for its successive validation on two different kind of organic solar cells.

1. Introduction

The development of an equivalent circuital model for Organic Solar Cells (OSC) has been subject of study since the first solar cells appear in various laboratories. This is due to a twofold need: on the one hand these models are important to compare the behaviour of OSC with Silicon based one; on the other hand they can be useful for the development of effective energy production systems based on OSC only or their integration with traditional photovoltaic plants. Moreover, the classic circuital models, widely used for Si-based solar cells, cannot be used directly, since the most recently developed OSC, based on perovskite or other organic semiconductors (Reenen et al., 2015; Xu et al., 2016; Wagenpfahl et al., 2010) exhibit under illumination conditions some deformations of I-V characteristics that influence their energy conversion capability (Ortiz-Conde et al., 2012; Gaur and Kumar, 2014; Wagner et al., 2012; Saive et al., 2013; Zuo et al., 2014; Romero et al., 2014). That behaviour, also known as S-shape or kink effect, has been widely addressed in literature and different circuital solutions were proposed to face it (a wide review can be found in García-Sánchez et al. (2017)). Recently a three-diode circuit has been proposed able to model different OSC with a high accuracy, also in the case of an evident S-shape effect in $I-V$ curves (García-Sánchez et al., 2013; Castro et al., 2016; Roland et al., 2016). Clearly, other than the fitting of single $I-V$ curves for assigned irradiance and temperature values, the three-diode circuit is of interest also to verify if it is possible to derive a dependence on irradiance (and temperature) for the parameters of that equivalent circuit in order to describe, by a unique lumped parameter circuit, the cell behaviour in all the operating conditions (i.e. from dark one up to 200 mW/cm^2). Despite the fact that the behaviour in dark conditions appears in most cases really similar at a first sight to the traditional single diode model widely used for c-Si based devices, building a sole circuital model actually useful taking into account dark and irradiance conditions is not a trivial problem. Recently on this issue some good results have been achieved and presented in the work of Tada (2017) for some OSCs, by using a circuit containing only two diodes. Unfortunately the two-diode model is not able to describe current-voltage curve for devices exploiting high non linear S-shape as the one used in this work. Then, the aim of this paper is to find a new dependence of the parameters for the three-diode circuit by starting from the study of the identification problem at different irradiance values and from the use of a suitable simplified model under the dark condition. The herein proposed dependence of the lumped parameters of three diode configuration on irradiance level, allows us to use a single circuit for the analysis of OSC under different operating conditions: this is the first step for the integration of OSC circuital model in photovoltaic system simulator, but at the same time can furnish a novel point of view for the advance of the OSC applied research.

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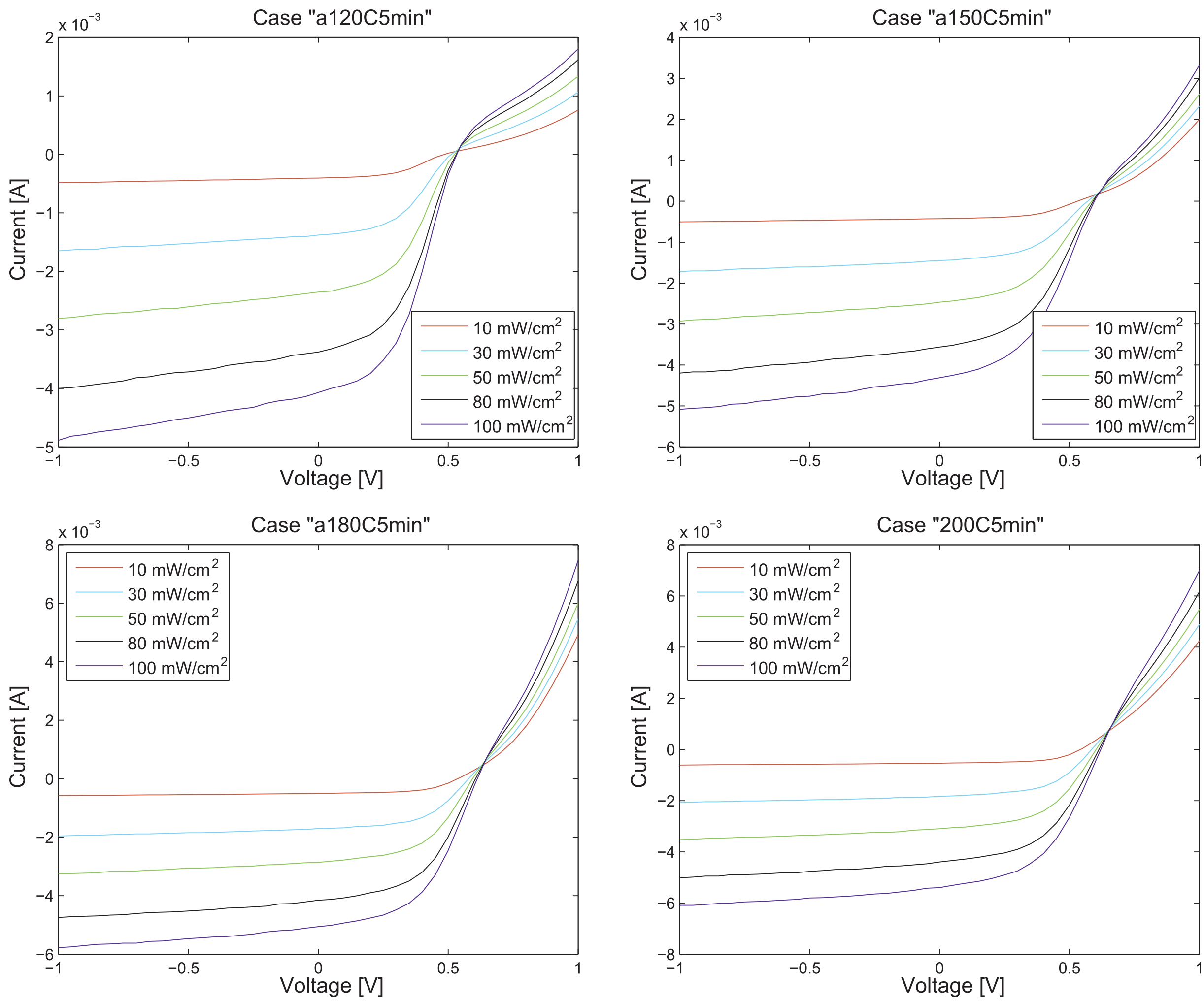

Fig. 1. Experimental OSC current-voltage curves at different insolation levels (from 10 mW/cm^2 to 100 mW/cm^2) for solar cells annealed at 120 °C, 150 °C, 180 °C, 200 °C for 5 min. It is worth noticing the non-ideal behaviour due to the strong S-shape effect.

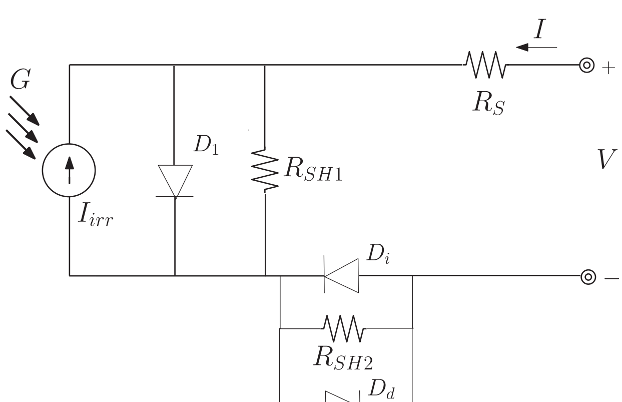

Fig. 2. Three-diode model for organic cells.

2. Measurements and experimental data

In our study we make use of solar cell devices consisting of an enhanced bi-layer of purified Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylene-vinylene] (MEH-PPV, M_n = 40,000–70,000, Aldrich) acting as electron donor and fullerene C60 (>99.95%, SES Research) acting as electron acceptor. Films were fabricated on cleaned ITO-coated glass coated with 50 nm of PEDOT:PSS (Aldrich, conductivity 1 S cm^{-1}) and subsequently coated with 50 nm of Al to serve as the cathode (Castro et al., 2006; de Castro et al., 2010). Sample fabrication and characterization was performed in inert N_2 atmosphere. Details of device sample preparation and characterization were reported previously (Castro et al., 2006; de Castro et al., 2010) and are out of the scope of this work. Thermal annealing at different temperatures was used to reduce the s-shape as previously described (de Castro et al., 2010). In this work we fitted curves of devices not annealed and annealed for 5 min at 120 °C, 150 °C, 180 °C and 200 °C. We refer to these samples as "not annealed " and a120C5min, a150C5min, a180C5min and a200C5min, respectively. It is worth noticing the presence of strong s-shape effects that have a tendency to disappear at low irradiance levels. As it is evident from Fig. 1 the current-voltage characteristic of these OSC presents significant modifications in behaviour according to its preparation and regions of operation. Although in the range voltage range 0–V_{OC} in some cases these curves are very similar to those of Si-C devices, it is also evident the strong nonlinear behaviour close to V_{OC} (see for example the case 120C5min in Fig. 1). This effect is typical of OSC having S-shape, but for these devices is also evident that, for voltage higher than V_{OC}, the current does not rise with a constant slope but instead with a exponential dependence. For these regions the devices cannot be modelled by means of simple two opposed diode model as done successfully for other devices by Tada (2017). On the other hand the introduction of a third diode allows to overcome this problem and, at the same time, modifies at minimum the shape of current-voltage characteristic for voltage values lower than V_{OC}.

For these samples experimental current-voltage curves at different