# EFFECT OF TEMPERATURE ON THE PARAMETERS OF A BULK HETEROJUNCTION ORGANIC SOLAR CELL

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**Abstract: This paper presents a theoretical study of the effect of temperature on the parameters of a novel polymer blend based organic solar cell, with a bulk heterojunction architecture. The variation of the short-circuit current density, the open-circuit voltage, fill-factor and power conversion efficiency with temperature will be analyzed.**

***Keywords:*** *organic semiconductor, organic solar cell, temperature, mobility.*

## I. INTRODUCTION

Organic solar cells (OPV) are of increasing interest for the solar energy industry, due to a set of crucial advantages they have compared to their inorganic counterparts, such as cost-effective fabrication methods [1, 2], and mechanical flexibility, which renders them suitable for a great number of applications [2, 3]. A wide range of materials have been developed for photovoltaic applications, such as organic polymers and oligomers [4] or liquid crystal-based composites [5-7].

Several OPV device architectures have been developed [7, 8]. The structure that is discussed here is the bulk heterojunction, which consists of a heterogeneous mix between a donor polymer and an acceptor polymer, which results in a non-uniform p-n junction, scattered within the entire volume of the active layer. This structure is illustrated in Figure 1.

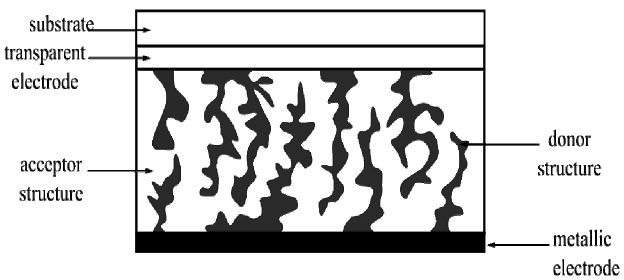


*Figure 1. Organic solar cell – bulk heterojunction structure [9]*

Organic photovoltaics still present one major drawback, which is their low power conversion efficiency, compared to their inorganic alternative [3]. This low efficiency is a consequence of the high degree of structural disorder characteristic to organic semiconductors [4, 7]. Because of their lack of structural order, organic semiconductors have low charge carrier mobility, an aspect which also affects device performance [8-12].

In organic semiconductors, mobility has been considered to vary with temperature following an Arrhenius-like law [4]. However, Bassler et al. has proposed in [13] a different relation which takes into consideration both the structural and the energetic disorder present in this class of materials. This paper presents a theoretical of open-circuit voltage, short-circuit current density, fill-factor, and power-conversion efficiency variations with temperature for a bulk heterojunction organic solar cell selected from literature [14], within a temperature range of 100-400 K.

## II. PHYSICAL MODEL

The organic solar cell selected [14] for this study has a bulk heterojunction obtained by mixing poly[2-methoxy-5-(2-ethylhexyloxy)]-1,4-phenylenevinylene (MEH-PPV) and [6.6]-phenyl $C_{61}$ butyric acid methyl ester (PCBM), with alternative electrode buffer layers of poly(3,4-ethylenedioxythiophene) (PEDOT), lithium fluoride (LiF), or aluminium (Al). The complete structure of the cell is ITO/PEDOT/MEH-PPV:PCBM(1:4)/LiF/Al [14].

The physical model of the device was deduced from the one diode equivalent circuit of a solar cell [15, 16]. This circuit is illustrated in Figure 2, and it contains a diode *D*, which models the p-n junction of the cell, a current source $J_L$, which represents the photocurrent, a shunt resistance $R_p$, which models the bulk defects of the active layer, and a series resistance $R_s$, which models both superficial and contact defects of the cell.

By applying Kirchhoff's laws on the circuit from Figure 2, the following equation for the total current density *J*, produced by the cell under illumination, is obtained [15, 16]:

$$J = J_0 \left\{ \exp\left[ \frac{e(U - R_s J)}{\gamma k_B T} \right] - 1 \right\} + \frac{U - R_s J}{R_p} - J_L \qquad (1)$$

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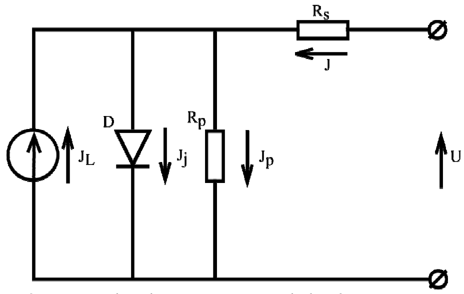


*Figure 2. One-diode circuit model of an organic solar cell, where $J_L$–photocurrent density of the cell, $J_j$-current density through diode D, $J_p$–current density through shunt resistance $R_p$, J-total current density produced by the cell under illumination [14-16]*

where $J_0$ is the dark saturation current density, $e$ is the elementary charge of a charge carrier, $\gamma$ is the ideality factor of diode $D$, $k_B$ is the Boltzmann constant, $T$ is the temperature of the cell, and $U$ is the output voltage of the cell. Equation (1) is transcendental, therefore its resolve requires numerical methods. In this work, the W Lambert function was considered [17-19].

Rough estimates of both series and shunt resistances, $R_s$ and $R_p$ respectively, can be obtained from the experimental $J$-$U$ curve of the cell, with the asymptotic approximation [16]. An illustration of this method is given in Figure 3.

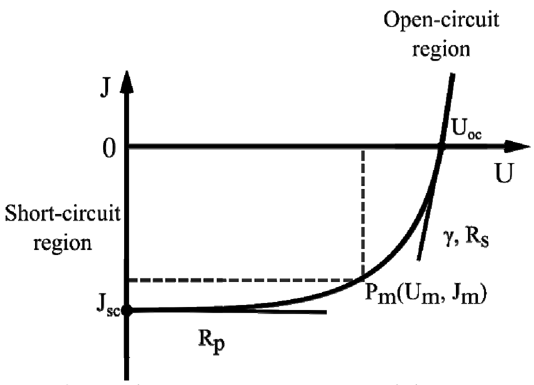


*Figure 3. Qualitative representation of the asymptotic approximation method for obtaining $R_s$ and $R_p$ values for a solar cell*

Equation (1) was resolved for temperatures within the range of 100-400 K, yielding a great number of theoretical $J$-$U$ characteristics. These characteristics represented the starting point for obtaining the variations of the following device parameters as functions of temperature: short-circuit current density $J_{sc}$, open-circuit voltage $U_{oc}$, fill-factor $FF$, and power-conversion efficiency $\eta$. Solar cell fill-factor $FF$ and power-conversion efficiency $\eta$ are given by equations (2) and (3), respectively:

$$FF = \frac{U_m J_m}{U_{oc} J_{sc}} \tag{2}$$

$$\eta = \frac{U_m J_m}{P_L} \cdot 100 = \frac{P_m}{P_L} \cdot 100 \tag{3}$$

where $P_L$ is the illumination power incident on the cell, $U_m$ and $J_m$ are the coordinated of the maximum power point $P_m$ on $J$-$U$ characteristic of the cell (see Figure 3).

## III. RESULTS AND DISCUSSIONS

Equation (1) was resolved with the W Lambert function in Matlab, for temperatures ranging from 100 K to 400 K. These simulations yielded several $J$-$U$ characteristics, from which the short-circuit current density $J_{sc}$, open-circuit voltage $U_{oc}$, the fill-factor $FF$, and the power-conversion efficiency $\eta$ were extracted, thus obtaining the variations of these parameters as functions of temperature.

The variations of the open-circuit voltage $U_{oc}$ and the short-circuit current density $J_{sc}$ as functions of temperature, for the studied cell, is given in Figures 4 and 5, respectively.

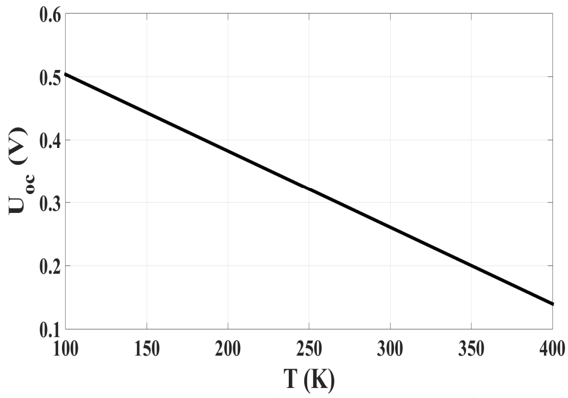


*Figure 4. Variation of the open-circuit voltage with temperature*

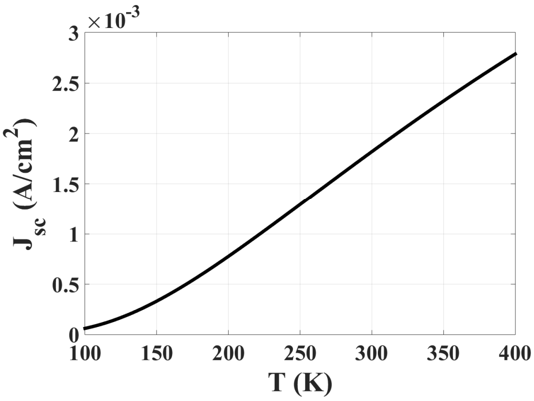


*Figure 5. Variation of the short-circuit current density with temperature*

The open-circuit voltage $U_{oc}$ decreases linearly with temperature. This behavior was encountered in several other organic solar cell prototypes [20, 21], yet its origin is still under debate. It has been argued [22, 23] that, for higher temperatures, $U_{oc}$ depends mostly on charge carrier recombination, thus yielding a linear dependency of temperature.

On the other hand, the short-circuit current density $J_{sc}$, increases strongly with temperature. Such a behavior was also reported for several organic solar cells [20]. $J_{sc}$ may be negatively influenced by recombination at high temperatures [20, 24], but it is predominantly dependent on the semiconductor mobility, which, in the case of organic semiconductors, is temperature-dependent. In organic

semiconductors, charge carrier transport predominantly relies on hopping mechanisms [25], which are temperature assisted. Therefore, charge carrier mobility is positively influenced by temperature, yielding and increase in current density [13, 20, 26].
Furthermore, the variations of cell's fill-factor and power-conversion efficiencies as functions of temperature were theoretically determined. The results are presented in Figures 6 and 7, respectively.

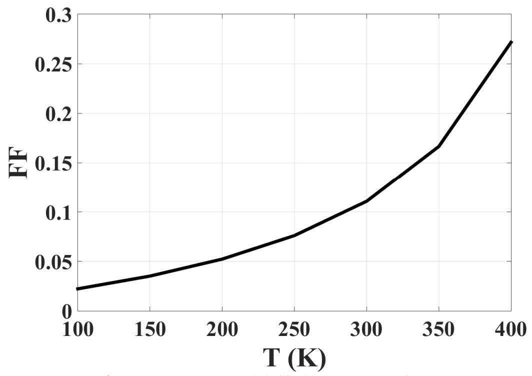


*Figure 6. Variation of fill-factor with temperature*

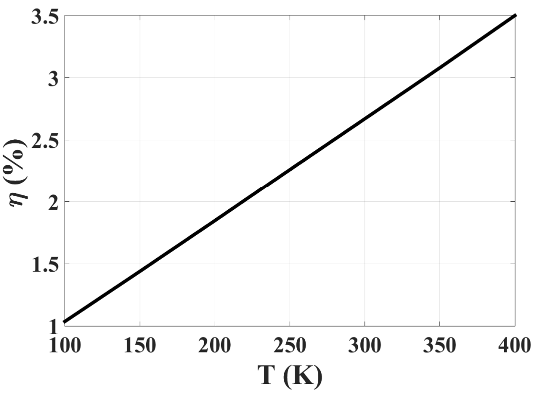


*Figure 7. Variation of power-conversion efficiency with temperature*

The fill-factor *FF* increases with temperature. Therefore, an increase in temperature is beneficial to the quality of the cell's *J-U* curve, also leading to an increase of the maximum power point Pm of the cell (see Figure 3).
The power-conversion efficiency $\eta$ increases strongly with temperature. Due to the increase of the fill-factor *FF* with temperature, the maximum power point $P_m$ also increases. Therefore, according to equation (3), an increase in the cell's maximum power yield $P_m$ leads to an enhanced efficiency $\eta$.
Such variations for both the fill-factor *FF* and the power-conversion efficiency $\eta$ are found in the literature [20]. It is argued that the prominent variations of short-circuit current density $J_{sc}$ and of fill-factor *FF* with temperature overshadow the weak decrease of open-circuit voltage $U_{oc}$ with temperature, thus causing the increase of power-conversion efficiency $\eta$. This explanation becomes more obvious if the following relation [20] for power-conversion efficiency $\eta$ is considered:

$$\eta = \frac{J_{sc} U_{oc}}{P_L} \cdot FF \quad (4)$$

## IV. CONCLUSIONS

This paper presents a theoretical study of the effects of temperature on the performance of an organic solar cell, fabricated with novel synthesized polymers, relying on a bulk heterojunction architecture. The solar cell in question was selected from the literature [14]. The study specifically focuses on the variation of the cell's characteristic parameters with temperature. By using the total current density equation, which was derived from the one-diode model of a solar cell, the short-circuit current density $J_{sc}$, open-circuit voltage $U_{oc}$, fill-factor *FF* and power-conversion efficiency $\eta$ were determined as functions of temperature, within the range of 100-400 K.
This theoretical study demonstrates that the MEH-PPV:PCBM blend is sensible to temperature variation, within the considered temperature range.
It shows that the open-circuit voltage $U_{oc}$ decreases with temperature. This variation is explained by the fact that open-circuit voltage is influenced by charge carrier recombination, at high temperatures.
The study also shows an increase of the short-circuit current density $J_{sc}$ with temperature. This behavior is mainly explained by the positive influence of the thermally-assisted charge-carrier transport in organic semiconductors over the current density.
The fill-factor *FF* also exhibits an increase with temperature. This variation demonstrates that an increase in temperature leads to an improved *J-U* characteristic and, therefore, to an increased maximum power-point $P_m$.
The study also yields an increase of the power-conversion efficiency $\eta$ with temperature. This behavior leads to the conclusion that an increase in temperature is beneficial to the cell's performance. However, it should be stressed upon the fact that this increase in efficiency is obtained within the range of 100-400 K. For temperatures above 400 K, effects such as thermalization and polymer damage must be considered.

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