Research on the Characteristics of Organic Solar Cells

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Abstract. Recently, organic solar cells are attracting a lot of attention due to flexibility, low cost, light weight and large-area applications, and significant improvement in the power conversion efficiency. But the efficiencies of organic solar cells are still lower than crystal silicon solar cells. By studying the photovoltaic properties of organic solar cells it is possible to influence the short circuit current (Isc), the open circuit voltage (Voc), the fill factor (FF), hence the cells efficiencies can be improved. First of all, the paper describes the characteristics of organic solar cell. Several characteristics impact on the conversion efficiency of organic solar cells, including the series resistance (Rs), the shunt resistance (Rsh) and so on. A circuit model of the solar cell provides a quantitative estimate for losses in the solar cell to interpret the characteristics of the solar cell. The conventional circuit model which is suitable for inorganic solar cells has emerged. However, compared with inorganic solar cells, organic solar cells are lack of a three-dimensional crystal lattice, different intramolecular and intermolecular interactions, local structural disorders, amorphous and crystalline regions, and chemical impurities. Therefore, an appropriate circuit model is represented in the paper.

1. Introduction
The worldwide consumption of energy has increased every year by several percentages over the last thirty years [1]. Nowadays, most of energy is supplied by fossil fuels on the one hand and by nuclear energy on the other hand. However, these resources are limited and their use has a serious environmental impact, which extends probably over several future generations. Solar light is the most important source of regenerative energy and represents mankind's only inexhaustible energy source. One of today's most promising tools to make use of solar energy is its direct conversion into electrical energy in photovoltaic cells [2]. The applied photovoltaic cells mainly are silicon-based solar cells in most cases. However, compared with traditional silicon-based solar cells, Organic solar cells are a promising way towards
large-area and low-price photovoltaic systems. The main advantages are the easy preparation, low process temperatures, low-cost materials and processing technology and the possibility to produce flexible devices on plastic substrates [3]. When the power conversion efficiency of organic solar cells is close to 10%, it can be served as an excellent candidate.

The low power conversion efficiency of organic solar cells confines its application. The power conversion efficiency was only 10-5% about thirty years ago. It is reported that the highest power conversion efficiency of polymer-based bulk-heterojunction solar cells is approach to 5% and the efficiency of small-molecule-based solar cells is up to 6.0% [4]. It is gratifying that there’s been a significant progress. It can encourage more and more people to go on research.

When researching organic solar cells, we should figure out the characteristics of organic solar cells and elements which impact on the power conversion efficiency of organic solar cells. An equivalent circuit of organic solar cells contributes to understand and analyze the characteristics of organic solar cells. This paper elaborates the characteristics of organic solar cells by analyzing equivalent circuits of organic solar cells.

2. Characteristics of organic solar cells

Organic solar cells and inorganic solar cells are based on photovoltaic effect. There are some well-known differences between organic solar cells and inorganic solar cells. Basically, compared with inorganic solar cells, organic solar cells are lack of a three-dimensional crystal lattice, different intramolecular and intermolecular interactions, local structural disorders, amorphous and crystalline regions, and chemical impurities. Obviously, when light absorption in inorganic solar cells, it leads to the formation of more free carriers, but when light absorption in organic solar cells, it leads to the formation of more excitons. Excitons have more binding energy in organic solar cells, and the mobilities of charge carriers are far lower in organic solar cells than in inorganic solar cells. As one of the many consequences of this, the power conversion efficiency of organic solar cells is much less than inorganic solar cells.

3. Equivalent circuit

3.1 Conventional equivalent circuit

![Conventional equivalent circuit of solar cells](image)

Figure 1. Conventional equivalent circuit of solar cells

Conventional equivalent circuit is usually adequate for describing characteristics of inorganic solar cells. Figure 1 shows conventional equivalent circuit of solar cells. $J_{ph}$ represents the photo-generated current, D is a diode which expresses current-voltage characteristics under dark condition, $R_s$ is the parasitic series resistance, $R_{sh}$ is the shunt resistance, $R_L$ is the load resistance, and $J_{ph}$ is the photo-generated current.
resistance, and \( V \) expresses the voltage of \( R_L \). The following equations which express conventional equivalent circuit can be derived from the Kirchhoff's Voltage Law and the Kirchhoff's Current Law.

\[
V = J_{sh} R_{sh} + J R_s
\]

(1)

\[
J + J_{ph} = J_D + J_{sh}
\]

(2)

\[
J_D = J_0 (e^{(V - J R_s)/n V_T} - 1)
\]

(3)

Solving above equations, we obtained the following equation:

\[
\ln\left(\frac{J + J_{ph}}{J_0} - \frac{V - J R_s}{J_0 R_{sh}} + 1\right) = \frac{V - J R_s}{n V_T}
\]

(4)

Where, \( J_0 \) is the saturation current density, \( n \) is the diode ideality factor, and \( V_T \) is the temperature potential.

The fourth equation is a transcendental equation. It is very difficult to solve the equation. Jain and Kapoor used Lambert W-function to solve the equation. It is proved that using Lambert W-function can make solving more previously [5].

3.2 Two-diode equivalent circuit

Two-diode equivalent circuit has been used to describe the characteristics of solar cells under illumination condition for thirty years. Figure 2 shows the two-diode equivalent circuit. We got the next equation from the Kirchhoff's Current Law.

\[
J = J_{ph} - \frac{V + J R_s}{R_{sh}} - J_{D1}[e^{B_1 (V + J R_s)} - 1] - J_{D2}[e^{B_2 (V + J R_s)} - 1]
\]

(5)

Where, \( B_1 = q/kT \), \( B_2 = B_1/n \).

\( D_1 \) diode stands for the electronic conduction phenomena in the quasi neutral region of the junction, such as diffusion, recombination, and the drift effect. \( D_2 \) diode represents the carrier recombination via deep levels in the space-charge region of the junction, with \( n = 2 \) for the approximation corresponding to the Shockley–Read–Hall recombination current density in the space-charge region. This model is consistent with the underlying physics of the electrical
characteristics and should give an accurate description of the real solar cell for low-level-injection conditions.

3.3 A simplified two-diode equivalent circuit
A central assumption in the conventional model is that photo-generated current $J_{ph}$ is constant for given incident light intensity and is independent of voltage. Mazhari put forward a simplified two-diode equivalent circuit. The central assumption of his viewpoint is photo-generated current $J_{ph}$ is a function of voltage. Figure 3 shows a simplified two-diode equivalent circuit. $R_{sh}^{int}$ represents loss due to polaron recombination and $R_{s}^{int}$ models charge extraction to the electrodes. Diodes $D_1$ and $D_2$ are ideal diodes that are like short circuit under forward bias and open circuit under reverse bias, respectively. Diode $D_{dark}$ represents the current-voltage characteristics of organic solar cells under dark condition. $V_{int}$ expresses the internal voltage.

![Figure 3. A simplified two-diode equivalent circuit of organic solar cells](image)

4. Discussion and conclusion
The single diode equivalent circuit usually is used to illustrate the characteristics of solar cells. It is a kind of simple understanding about characteristics of solar cells. Compared other kinds of solar cells, organic solar cells have unique properties. The two-diode equivalent circuit has occurred for thirty years. It considers low-level-injection conditions in short. The injection level of organic solar cells is low, which is in favor of more precise illustrating the characteristics of organic solar cells. The third circuit considers more factors. B. Mazhari has proven that his method is adequate to depict the characteristics of organic solar cells.

When measuring solar cells, temperature is 25°C and light intensity is 100mW/cm², which are International measuring standards. Ali Cheknane et al made a measuring experiment. They chose an MEH-PPV. It is proven that the single diode equivalent circuit is not adequate to depict the characteristics of organic solar cells. When light intensity is 100mW/cm², the third equivalent circuit stands for elaborating the characteristics of organic solar cells.

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