Modeling large-area solar cells

B. Kippelen, S. Choi, W.J. Potscavage Jr.
Center for Organic Photonics and Electronics, School of Electrical and Computer Engineering,
Georgia Institute of Technology, Atlanta, GA 30332

Abstract: **In this talk we will discuss the modeling of large-area organic solar cells. Degradation of the performance with increased area is observed and analyzed in terms of the power loss density concept. The equivalent circuit model is used to verify that a change in power loss density (or R_SA) can have a strong influence on device performance. The limited sheet resistance of ITO is found to be one of the major limiting factors when the area of the cell is increased. The effective series resistance of the ITO film can be minimized by integrating metal grids and the improvement is analyzed using a power loss density analysis. By integrating metal grids onto ITO, the series resistance could be reduced significantly yielding improved performance.**

I. INTRODUCTION

Organic photovoltaics have received great interest in recent years due to the promising potential for the development of large-area, low-cost, light-weight solar modules with highly flexible form factors [1]. Significant efforts have been focused on improving the power conversion efficiency through the synthesis of new light-harvesting molecules and polymers [2]. However, less attention has been given to understanding how the power conversion efficiency scales with device area, and reports dealing with this important issue are relatively scarce.

The power conversion efficiency is defined by:

$$\eta = \frac{J_{\max} V_{\max}}{P_{\text{inc}}} = FF\frac{J_{\text{SC}} V_{\text{OC}}}{P_{\text{inc}}}, \tag{1}$$

where P_{inc} is the incident power density, $J_{\max}$ and $V_{\max}$ are the current density and voltage, respectively, at which the maximum power is generated in the device, *FF* denotes the fill factor, J_{SC} is the short-circuit current density, and V_{OC} is the open-circuit voltage.

Like all electronic devices, solar cells exhibit series resistances. Hence, some generated power will be lost by dissipation through the internal resistance of the device. Therefore, another important quantity to consider in the optimization of the efficiency of a cell is the total resistive power loss per unit area P_{R} which is given by:

$$P_{\text{R}} = \frac{R_{\text{S}} I_{\max}^2}{A} = \frac{R_{\text{S}}(J_{\max} A)^2}{A} = R_{\text{S}} A J_{\max}^2, \tag{2}$$

where R_{S} is the series resistance in the device and A is the area of the device. Eq. (2) clearly illustrates that the resistive power loss per unit area is proportional to the series resistance ($R_{\text{S}}A$) and that consequently the effects of parasitic series resistance are likely to play a more prominent role as the area of the cell is increased. Therefore, methods are needed to evaluate this power loss and relate it to the performance of large-area organic solar cells.

II. POWER LOSS ANALYSIS

Knowing where power is lost in a solar cell and how the device geometry and structure affect the power loss and series resistance is important for the design of large-area solar cells. The resistive power loss density depends on the resistance of the electrodes and the organic semiconductors, and the contacts between film interfaces, and is given by:

$$P_{\text{R}} = P_{\text{ITO}} + P_{\text{organic}} + P_{\text{contacts}} + P_{\text{Al}} \tag{3}$$

where P_{ITO} and P_{organic} are the resistive power loss densities of the ITO and organic semiconductors, respectively. P_{contacts} include all the interfacial contact power loss densities between films, such as metal-organic and organic-organic interfaces. P_{Al} is the resistive power loss of the cathode, which is aluminum in this case. For a device structure as shown in Fig. 1, the power loss density of the ITO layer (P_{ITO}) is given by:

$$P_{\text{ITO}} = \frac{1}{\alpha} J_{\max}{}^2 L^2 R_{\text{sheet-ITO}} \tag{4}$$

where $R_{\text{sheet-ITO}}$ is the sheet resistance of the ITO in Ω/sq., L is the length of the solar cell, and α is determined by the number of interconnect contacts. It is assumed that all of the generated current flows in a direction normal to the edge. Therefore, solar cell width (W) does not affect the power loss density. It was shown that the ITO is the only component attributing to area-scaling property of organic solar cells assuming negligible resistive loss of contacts and metal cathode (Al) [3]. Equations (4) shows that the power loss density from the ITO depends on the length of the active area along which photogenerated current flows. In fact, power loss density increases with area only when the photogenerated current flows in the x-y plane of the active area, *i.e.*, the ITO or cathode, since increasing the active area makes the photogenerated current travel a longer distance before it is collected at the external electrodes, thereby increasing series resistance.

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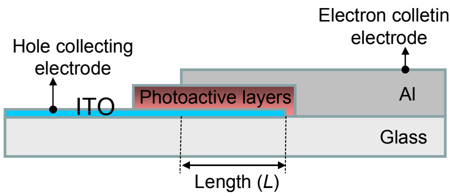

Fig. 1. Typical organic solar cell geometry.

Resistive power losses affect the performance of the solar cell by increasing the series resistance, which is given by rewriting Eq. (2):

$$R_S A = \frac{P_R}{J_{max}^2} \tag{5}$$

At a given photogenerated current density, the value of $R_S A$ is proportional to the resistive power losses.

Because of the dependence on L^2 from the ITO component, $R_S A$ will increase with the length of the device. It is well known that the series resistance is a parameter which can limit the performance of a solar cell by reducing both *FF* and photocurrent for both inorganic and organic solar cells [3].

The effective series resistance of the ITO film can be minimized by integrating metal grids and the series resistance is given by Eq (6):

$$R_S^{grid} A = \frac{1}{12} s^2 R_{sheet\text{-}ITO} \tag{6}$$

The metallic grids consist of finger electrodes branching out from a busbar electrode. When the grid is included, the ITO resistance scales only with the spacing between the finger electrodes *s* instead of with the length of the entire device *L*. Thus, the contribution to resistance from the ITO for a large-area device can be significantly decreased and will not depend on area when a grid is used as long as the finger electrode spacing is small. Power loss densities of a solar cell with an integrated metal grid can be calculated based on the unit cell concept. The unit cell is defined such that the total photogenerated current leaves the unit cell only through the busbar and no photogenerated current flows across any of the unit cell edges.

In addition to the resistive power losses of the ITO and organic semiconductors, the metal grid structure introduces additional power losses such as contact loss between the ITO and the grid, resistive power losses from the grid itself, and a shadow power loss. The shadow power loss is associated with shadow areas which are created by the metal grid blocking incoming sunlight. It was shown that metal grids improved the performance of large-area organic solar cell despite of these additional power losses by reducing significant amount of resistive power loss from the ITO [3].

III. EQUIVALENT CIRCUIT MODELING

The equivalent circuit consists of a diode, a dc current source, a shunt resistance, and a series resistance. It can be used to verify that a change in series resistance can have a strong influence on device performance by varying $R_S A$ and holding the other parameters constant. Fig. 2 illustrates how changing the $R_S A$ affects the shape of the *J-V* curves using the model parameters for the large-area device. The graphs show that J_{SC} and the current density and voltage at which maximum power is produced are all lowered as $R_S A$ increases substantially. These effects result in a lower maximum power output and *FF* for the cell, therefore decreasing the efficiency. To design efficient solar cells with large areas, the mechanisms that contribute to the series resistance and power loss as cell area is increased must be understood.

IV. CONCLUSIONS

It has been shown that the equivalent circuit model and series resistance analysis are comprehensive tools to understand the area-scaling performance of organic solar cells. Provided the cathode, Al in this case, is highly conductive and thick, the analysis indicated that the series resistance contribution from the ITO was the only area-scaling component of the organic solar cell, therefore limiting power conversion efficiency as solar cell area increases. Ideally, the performance of solar cells with a grid should not depend on the area as long as the cell keeps the same unit cell dimension with negligible grid resistance as the area increases.

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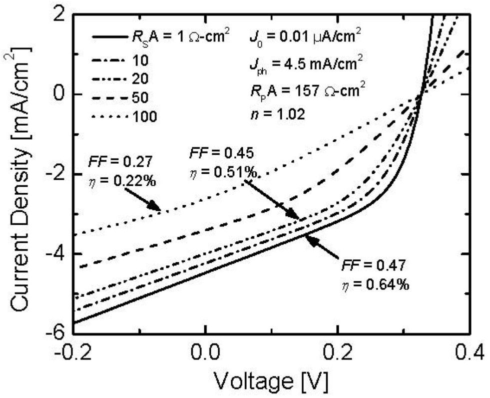

Fig. 2. Effect of series resistance ($R_S A$) on organic photovoltaic performance [3].