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Designing of Organic Solar Cell Module for Obtaining Maximum Performance

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1. Introduction

Nowadays, organic solar cells (OSCs) attract attention as a renewable energy, their low cost, light, colorful, and flexibility [1-3]. OSCs with the high power conversion efficiency (*PCE*) beyond 7 % are reported [4, 5]. However, active areas of these devices were less than 1 cm^2. To industrialize OSCs, these device sizes were too small. Modularization of OSCs is designed over 100 cm^2 for substrate size. However, the high resistance of the transparent conductive oxide (TCO) is a problem when the device areas are large. To achieve high-performance OSC modules using the TCO, optimization of the TCO is necessary.

In this work, influence of active areas of OSC devices using Indium-Tin-Oxide (ITO) glass substrate was studied. We have examined the correlation between the solar cell characteristics and resistance of ITO glass substrate. And, the equivalent circuit model simulation was performed to investigate the influence of resistance.

2. Experimental

2.1. Device fabrication

The ITO glass substrate (Sanyo Vacuum Industries Co., Ltd., about 10 Ω/square) with the size of 30 x100 mm^2 was used. At first, to clean and smooth their surface, ITO glass substrate was treated using oxygen plasma. As a hole transport layer, an approximately 30 nm poly(3, 4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS) layer (Baytron P PV. Al4083, H. C. Starck Ltd.) was deposited on an ITO glass by spin coating (3000 rpm, 180 sec). The substrate was dried on hot plate (135°C, 10 min) in air [6]. Regioregular poly(3-hexylthiophene) (P3HT, Merck, 20 mg/ml) used as a *p*-type semiconductor and phenyl C61 butyric acid methyl ester ([60]PCBM, Frontier Carbon Corp., 14 mg/ml) used as a *n*-type semiconductor were dissolved in chlorobenzene (CB). All materials were used without further purification. Organic thin film was deposited for P3HT:[60]PCBM mixture solution by the spin coating method (2000 rpm, 120 sec, and approximately 100 nm thick). Approximately, 120 nm aluminum top electrode was deposited in vacuum on the organic layer. Thermal annealing treatment on a hot plate (110°C, 10 min) was carried out in the glove box filled with nitrogen.

2.2. Measurements

The *PCE* and the maximum output power (P_{max}) were calculated from solar cell parameters, which were derived from current density versus voltage (*J-V*) characteristics under air mass 1.5 global solar simulated light irradiation

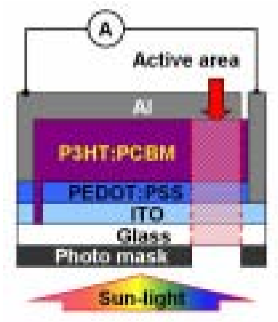

Fig. 1 The structure of OSC device. Active area (shadow area) was controlled by photo-mask.

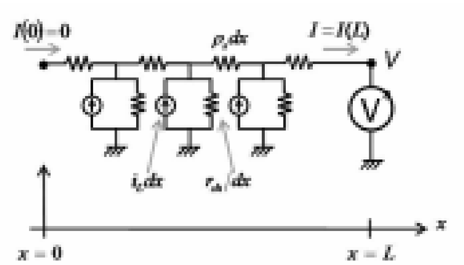

Fig. 2 The simulation by equivalent circuit model.

(AM1.5G, 100 mW/cm^2, Bunkoh-Keiki Co., Ltd.). The *J-V* characteristics were measured using a Keithley 2400 source measurement unit at room temperature in air.

The active area of OSCs, was controlled by the photo-mask from 1.0 cm^2 to 8.0 cm^2 (Fig. 1).

2.3. Influence of series resistance

To design the OSC module for obtaining maximum performance, influence of series resistance of ITO on current density was simulated by equivalent circuit model without diode component (Fig. 2). This simple model is generally used for conventional solar cells (i.e. monocrystalline silicon solar cell, multicrystalline silicon solar cell, and amorphous silicon solar cell.) The current (I_{sc}) depending on active area of OSC module is simulated by the following equation:

$$Isc = \frac{V_a - r_{sh} i_L}{\sqrt{\rho_s r_{sh}}} \tanh\left(\sqrt{\rho_s / r_{sh}}\, L\right) \qquad (1)$$

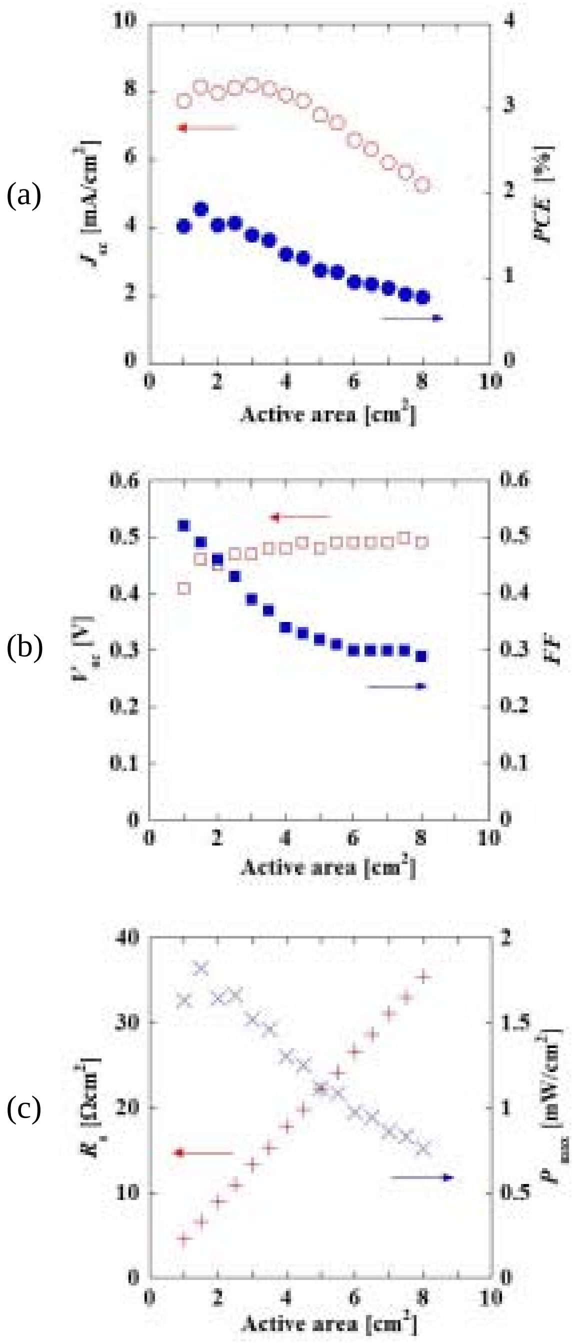

Fig. 3 The solar cell characteristics of active areas from 1.0 to 8.0 cm^2; (a): the J_{sc} and the PCE values, (b): the V_{oc} and the FF values, (c): the R_s and the P_{max}.

$$P = \frac{V_a - r_{sh} i_L}{\sqrt{\rho_s r_{sh}}} V_a \tanh\left(\sqrt{\rho_s / r_{sh}}\, L\right) \qquad (2)$$

Here V_a is applied voltage of the cell, L is length of the cell, ρ_s is the series resistance, r_{sh} is shunt resistance, and i_L is the current value in module. The power of cells in the module is determined by using eq. 2.

3. Results and discussion

The influence of resistance of ITO glass substrate on solar cell characteristics was studied. Fig. 3 shows solar cell characteristics for active areas from 1.0 to 8.0 cm^2. Up to 4.0 cm^2 active area, J_{sc} was kept the constant value, however, J_{sc} decayed when active area was over 4.0 cm^2. Similarly, the PCE value decayed with active areas over 3.0 cm^2 (Fig. 3-(a)). On the other hand, the V_{oc} value was constant value in this range. The FF value was monotonically decreased with increasing active area (Fig. 3-(b)). The R_s value was monotonically increased with increasing active area (Fig. 3-(c)). Finally, P_{max} turns to decrease at 3.0 cm^2 active areas. Therefore, to obtain the sufficient P_{max}, active area must be designed within 3.0 cm^2 or less.

3. Conclusions

To design OSC modules for obtaining maximum performance, influence of active areas of OSC device using ITO glass substrate of 10 Ω/square was studied. The J_{sc} and the FF values were monotonically decreased with increasing active area because of increasing series resistance. The P_{max} value decayed with active area over 3.0 cm^2. The OSC module must be designed for active area within 3.0 cm^2 when the ITO with 10 Ω/square is used.

Acknowledgements

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