F-1-4

Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp114-115

Accurate derivation of all parameters of the single diode model from a single current-voltage characteristic of a solar cell using an extensively valid and stable iterative calculation method

Mohammad M. Rahman, Ryota Kojima, Ken-ichi Ishibashi, Yasuo Kimura, and Michio Niwano

Laboratory for Nanoelectronics and Spintronics, Research Institute of Electrical Communication, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

1. Introduction

The solar cell is a very useful device for clean electric power generation and its performance has been continuously improved through intensive research in this field. A solar cell is generally characterized using the equivalent circuit of the single diode model as shown in Fig. 1 and the relation between the current I and the voltage V is given by

$$I = I_{ph} - I_0\left[\exp\left\{\frac{q(V+R_sI)}{nk_BT}\right\}-1\right]-\frac{V+R_sI}{R_{sh}}, \qquad (1)$$

where I_{ph}, I_0, R_s, R_{sh}, q, ,n, k_B, T are the photocurrent, the saturation current of the diode, the series resistance, the shunt resistance, the electron charge, the ideality factor, the Boltzmann constant, and the temperature, respectively. The equivalent circuit includes many parameters. Each value of the parameters shows characteristics of each element in a solar cell and can be made a diagnosis of a solar cell. Especially, the diagnosis is essential in the development of a new type of solar cell such as an organic solar cell [1] or a dye-sensitized solar cell [2, 3]. Therefore, it is crucially important to precisely estimate all the parameters of a solar cell for improvement of its performance. Many meathods for determining the parameters of a solar cell have been already reported [4]. However, most of the previously reported methods neglect a shunt resistance R_{sh} or requires an assumption that is valid under only a special condition. Here, we have proposed a new extensively valid and stable method for estimating all the parameters of a solar cell.

2. Theory

Our method requires only one assumption, which follows:

$$\Delta \equiv \exp\left\{-\frac{q(V_{oc}-R_sI_{sc})}{nk_BT}\right\} << 1, \qquad (2)$$

where V_{oc} is the open circuit potential. The assumption (2) is generally valid enough for various solar cells. Under the assumption (2), $-dV/dI$ is given by

$$-\frac{dV}{dI} = \frac{nk_BT}{I_{sc}-I-\{V-R_s(I_{sc}-I)-nk_BT/q\}/R_{sh}}+R_s. \qquad (3)$$

in order to determine the ideality factor n and the series resistance R_s, temporary parameters R_{s0} and n_0 are introduced to Eq. (3), which yields

$$-\frac{dV}{dI} = \frac{nk_BT/q}{I_{sc}-I-\frac{V-R_{s0}(I_{sc}-I)-n_0k_BT/q}{R_{sh}}(1-\delta)}+R_s, \qquad (4)$$

where δ is defined by

$$\delta \equiv \frac{(R_s-R_{s0})(I_{sc}-I)+(n-n_0)k_BT/q}{V-R_{s0}(I_{sc}-I)-n_0k_BT/q}. \qquad (5)$$

When $|\delta|<<1$, Eq. (4) is given by

$$-\frac{dV}{dI} = \frac{nk_BT/q}{I_{sc}-I-\{V-R_{s0}(I_{sc}-I)-n_0k_BT/q\}/R_{sh}}+R_s. \qquad (6)$$

The condition, $|\delta|<<1$ can be valid when the parameters,

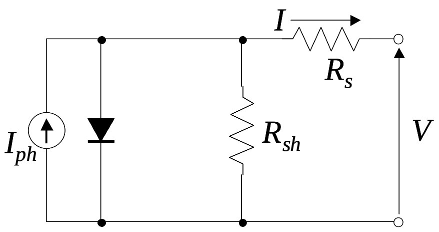

Fig. 1: The equivalent circuit (single diode model) of a solar cell.

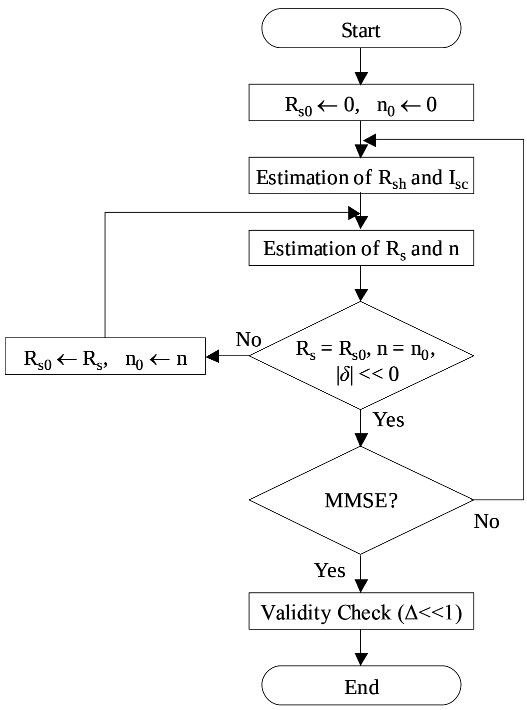

Fig. 2: The flow chart of our method employed to derive the values of solar cell parameters.

R_{s0} and n_0 are close in value to the series resistance R_s and the ideality factor n, respectively. Note that the series resistance R_s and the ideality factor, n disappear from the denominator in the right-hand side of Eq. (6) by introducing the temporary parameters R_{s0} and n. Then, the series resistance R_s and the ideality factor, n are derived by the y-intercept and the slope of the plot of $-dV/dI$ as a function of $[I_{sc}-I-\{V-R_{s0}(I_{sc}-I)-n_0k_BT/q\}/R_{sh}]^{-1}$ under the condition $|\delta|<<1$, respectively. In order to find the appropriate values of the temporary parameters, the estimation of series resistance, R_s and the ideality factor, n according to Eq. (6) is iterated using 0 as the initial value of each temporary parameter as shown in Fig. 2. On the other hand, from Eq. (6), the initial value of the shunt resistance R_{sh} is given by

$$-\left.\frac{dV}{dI}\right|_{I=I_{sc}} = R_{sh} + R_s \sim R_{sh}\,. \qquad (7)$$

At the first iteration count of the loop, the values of the series resistance, R_s and the ideality factor, n include large errors because $|\delta|<<1$ is not generally satisfied when R_{s0} = 0 and n_0 = 0. However, they are close to the appropriate values as compared with the initial ones, respectively. More accurate values are obtained by using the values of the series resistance, R_s and the ideality factor, n given at this step as those of R_{s0} and n_0. The most appropriate values are finally yielded by repeating this procedure until $R_s = R_{s0}$, $n = n_0$, and $|\delta| = 0$ as shown in Fig.2.

3. Application to analysis of solar cells

Figure 3 shows the experimental *I-V* curve of an organic solar cell with triple heterojunctions (solid line) [1] and the *I-V* curves calculated using the value of the parameters derived by our method (broken line) for instance. The calculated *I-V* curve was in excellent agreement with the experimental data, to the extent that they could not be distinguished from each other. The values of parameters of another solar cell determined by using our method and previous method are compared to each other in Table I. It is clearly seen that our method is adaptable for analysis of various kinds of solar cells.

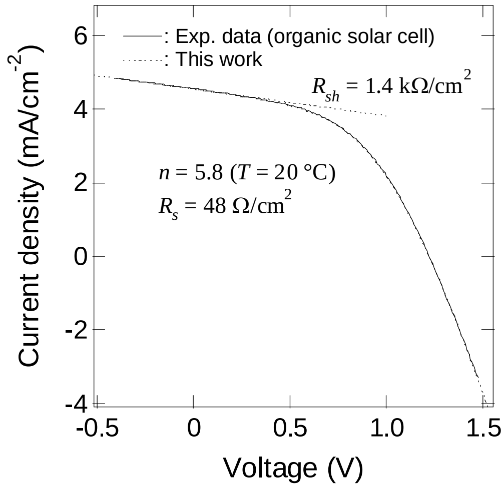

Fig. 3: The experimental *I-V* curve of an organic solar cell with triple heterojunctions (solid line) [1] and the *I-V* curves calculated using the value of the parameters derived by our method (broken line).

4. Conclusions

We have proposed a stable method for deriving all the parameters from a single *I-V* curve, which requires only the valid assumption for a general solar cell. We have demonstrated that our method is very stable and is adaptable for analyzing various solar cells. Our extensively valid and stable method is very useful for analyzing various new solar cells, leading to an improvement of their performance.

References

[1] A. Yakimov and S. R. Forrest, Appl. Phys. Lett. **80** (2002) 1667.

[2] Masaki Murayama and Tatsuo Mori, Jpn. J. Appl. Phys. **45** (2006) 542.

[3] Masaki Murayama and Tatsuo Mori, Thin Solid Films **509** (2006) 123.

[4] P. Mialhe, A. Khoury, and J. P. Charles, phys. stat. sol. (a) **83** (1984) 403.

[5] T. Easwarakhanthan, J. Bottin, I. Bouhouch and C. Boutrit, Int. J. Solar Energy **4** (1986) 1.

[6] M. Chegaar, Z. Ouennouchi, and A. Hoffmann, Solid-State Electron. **45** (2001) 293.

[7] V. N. Singh and R. P. Singh, J. Phys. D **16** (1983) 1823.

Table I: The values of solar cell parameters derived by our method and the previous work, previously and Δ.

Cell or Module	V_{oc} (V)	I_{sc} (A)	I_{ph} (A)	I_0 (μA)	R_s (Ω)	R_{sh} (kΩ)	n	T (°C)	Δ
Si (R.T.C France) [a]	0.5728	0.7608	0.7608	0.3223	0.0364	0.0538	1.484		8.9×10^{-7}
A previous work [b]	–	–	0.7609	0.4039	0.0364	0.0495	1.504	33	–
This work	0.57	0.76	0.77	0.20	0.037	0.032	1.4		5.6×10^{-7}
Si (Photowatt-PWP-201) [a]	16.778	1.030	1.0318	3.2876	1.2057	0.549	48.450		8.3×10^{-6}
A previous work [b]	–	–	1.0359	6.77	1.146	0.2	51.32	45	–
This work	17	1.0	1.0	2.3	1.3	0.83	47		6.3×10^{-6}
Silicon [c]	–	0.0500	–	–	3.3	–	2.5	17	3.4×10^{-3}
This work	0.52	0.050	0.050	0.99	0.73	0.16	1.9		4.5×10^{-5}
Organic solar cell [d]	–	–	–	–	–	–	–	–	–
This work	1.2	0.0046	0.0047	0.92	48	1.4	5.8	20*	1.1×10^{-3}
DSSC(C4) [e]	0.704	0.00206	-	0.035	43.8	3.736	2.5	–	–
This work	0.70	0.0021	0.0021	0.023	42	3.2	2.5	20*	4.9×10^{-5}

[a] See Ref.[5] , [b] See Ref.[6], [c] See Ref.[7], [d] See Ref.[1], [e] See Ref.[2]

* No information on the temperature, T in the reference.