INFLUENCE OF EXTERNAL CONDITIONS ON PARAMETERS OF SILICON SOLAR CELLS

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Abstract: The purpose of the work is the investigation of influence of rapid change of temperature and the shadowing of light on silicon solar cells operation. Current-voltage characteristics for multicrystalline silicon solar cells were measured by the use of computer controlled global spectrum sun simulator under an AM 1.5. The measurements of I-V characteristics allow the determination of basic electrical parameters and efficiency using the double exponential relationship from two-diode solar cells model. Temperature measurements were carried out in the temperature range from 5 to 55°C under constant irradiance. Under changeable area of illumination of solar cells was also observed the variation of their parameters. The rate of decrease of solar cells efficiency with temperature and shadowing area are important to estimate optimal working conditions of PV systems.

Keywords: *silicon solar cell, I-V characteristic, two diod model, efficiency of solar cell*

1. INTRODUCTION

One of the most important methods to characterization of solar cells is the analysis of current-voltage (I-V) characteristic. An equivalent electrical circuit contains several parameters related to physical phenomena occurring in solar cell. These parameters give the important information about the environmental conditions and manufacturing processes and the performance of solar cells [1].

To describe the performance of solar cells the known two-diode model with diffusion and recombination transport mechanism was adopted [2 - 3]. A model with seven parameters is given by equation:

$$I = I_{ph} - I_{s1}\left[\exp\left(\frac{V + I \cdot R_S}{A_1 V_t}\right) - 1\right] - I_{s2}\left[\exp\left(\frac{V + I \cdot R_S}{A_2 V_t}\right) - 1\right] - \frac{V + I \cdot R_S}{R_{sh}} \quad (1)$$

where:
I and V – the cell terminal current and voltage, respectively; I_{ph} – generated photocurrent; R_S – series resistance; R_{sh} – shunt resistance; A_1 and A_2 – diode ideality factors; I_{s1} and I_{s2} – saturation currents.
V_t is equal to kT/e (e = $1.6 \cdot 10^{-19}$ C). A_1 equal 1.0 and A_2 equal 2.0 were chosen [1, 4].

The authors of work [5] call attention that irradiance level as well as weather conditions such as ambient temperature and wind speed have an effect on the operating temperature of PV module. Solar cell performance was clearly influenced by temperature. It was reported in literature [6] that as cell temperature increases the open circuit voltage decreases. Short circuit current lightly increases. This phenomenon is due to a bandgap shift [7]. The decrease of absorption coefficient with temperature is also reported. Fill factor similarly to voltage decreases proportionally, but there is no a simple mechanism, which may explain its temperature dependence [6 – 7]. However the temperature behaviour of solar cells parameters is well known the experimental research of solar cells in various ambient temperatures is very important. The examination of solar cells in laboratory conditions is indispensable to predict their behavior in ambient conditions.

2. EXPERIMENTAL

Current-voltage characteristics for solar cells of area 100 cm^2 were measured by the use of computer controlled global spectrum sun simulator under an AM 1.5 (1000 W/m^2) (I-V Curve Tracer For Solar Cells Qualification, v 4.1.1) Fig. 1. Solar cells used in these measurements were based on multicrystalline silicon of 300 μm thick, 1 Ωcm resistivity, p-type (boron doped). The measurements of I-V characteristics allow us to determine the basic parameters like: I_{SC} – short circuit current, V_{OC} – open circuit voltage, FF – fill factor and η – efficiency. The I-V curves were fitted with the double exponential relationship given by the equation (1). Silicon solar cells with TiO_2 and a-Si:N:H antireflective coatings were measured in changeable temperature and degree of darkening. Temperature measurements were carried out under constant irradiance in the temperature range from 5 to 55^{o}C. Experimental set-up allows

Fig. 1. Photos of I-V Curve Tracer For Solar Cells Qualification: a) general view, b) „table" with solar cells under four probes during measurement.
Rys. 1. Zdjęcia aparatury do pomiarów charakterystyk prądowo-napięciowych I-V (Curve Tracer For Solar Cells Qualification): a) widok ogólny, b) „stolik" z ogniwem słonecznym, podczas pomiaru czteropunktowego.

easy control of temperature of the measuring table in the range from 0 to 60 ^{o}C. In case of slow temperature changes the user may perform current-voltage characteristics at chosen temperature and automatic data acquisition. Solar cells heating and cooling during measurements was realized by four Peltier modules with water system. Each of the four Peltier has its own temperature sensor and system protecting the set-up against overheating. The shadow variation was realized by the limitation of irradiative area of cells by the use of mechanical diaphragm. The shadowing of the cells is also the reason of deterioration of their electric parameters [8]. The analysis of shadowing of solar cell may be useful for designing PV system in real condition. The places for future location of solar panels should characterize high air flow and stabile temperature [9 – 10].

3. RESULTS AND DISCUSSION

The temperature is very important parameter for choosing places of future solar cells application. I-V characteristics analysis shows that the changes of short circuit current are insignificant and it can be attributed to the increased light absorption due to a decrease in the band gap of silicon [10]. Fig. 2 clearly shows decrease in efficiency of solar cell and open circuit voltage with rising temperature. Solar cells efficiency apparently decreases at high temperature above 40-55^{o}C.

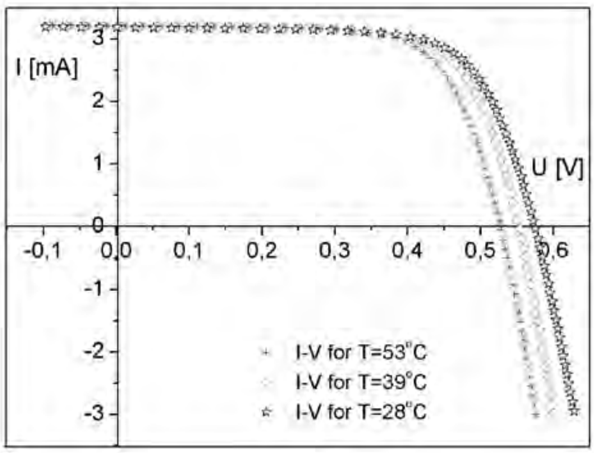

Fig. 2. The I-V characteristics of multicrystalline silicon solar cell at different temperatures (for irradiation on full area of solar cell).
Rys. 2. Charakterystyki prądowo-napięciowe ogniw słonecznych dla różnych temperatur (przy równomiernym oświetleniu całej powierzchni ogniwa).

In Fig. 3 is clearly shown that the shadowing of solar cell area decreases both η and I_{SC}. Even very small shadowing of about 4% causes the strong decrease in efficiency and short circuit current. This behavior is non linear. These parameter (η, I_{SC}) are strongly influenced by the shadowing factor which makes this relation non proportional to the value of photon flux. In our opinion this may be explained by the major influence of diode current in non illuminated area of solar cell. The open circuit voltage is rather insensitive on the shadowing factor.

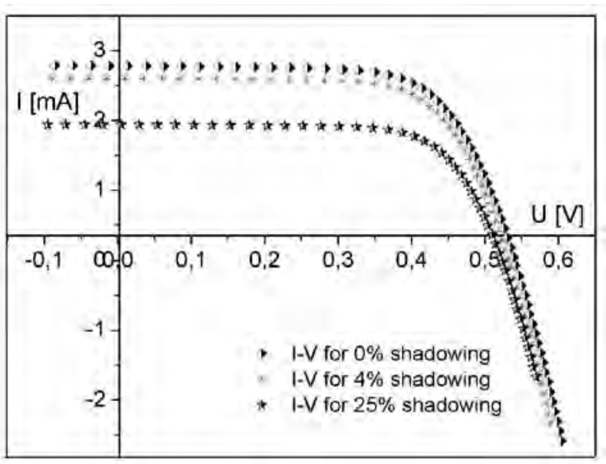

Fig. 3. I-V characteristics of multicrystalline silicon solar cell with different shadowing area (at room temperature about 25°C).
Rys. 3. Charakterystyki prądowo-napięciowe ogniw słonecznych dla różnego stopnia zacienienia ich powierzchni (w temperaturze pokojowej ~ 25°C).

Tab. 1 includes values of the main parameters of solar cells with two kinds of ARC for chosen temperatures and shadowing areas. These values confirm an observation from Fig. 2 that temperature has not a fundamental influence on I_{SC} and changes in shadowing area are no importance for V_{OC} – Fig. 3. It means if we have PV system of high efficiency we must assure conditions of solar cells work with stable temperature, rather under 35°C and with minimal shadowing. The shadowing area plays the role of shunt resistors and diode effectively decreasing of current flow through the solar cells. It reflects fill factor increase.

The temperature dependence of efficiency η and open circuit voltage V_{OC} is presented in Fig. 4. The decrease in η is mainly due to the decrease in V_{OC} which is consisted with the theoretical announcements [6].

Fig. 5 shows the dependence of η and I_{SC} on shadowing area of solar cell. The strong influence

Table 1. The main parameters of solar cells for chosen temperatures T and shadowing areas A_S.
Tabela 1. Najważniejsze parametry ogniw słonecznych dla wybranych temperatur T i różnej powierzchni zacienienia A_S.

Multicrystalline silicon solar cell with TiO_2 ARC									
T [°C]	η [%]	V_{OC} [mV]	I_{SC} [A]	FF	A_S [%]	η [%]	V_{OC} [mV]	I_{SC} [A]	FF
25	14.00	593.4	3.24	0.727	0	10.15	539.8	2.78	0.677
32	13.15	573.1	3.18	0.721	4	9.42	526.3	2.62	0.688
37	12.91	558.3	3.17	0.717	10	8.37	522.6	2.31	0.693
46	12.35	544.9	3.20	0.704	25	6.86	518.7	1.90	0.702
53	11.85	527.8	3.21	0.696	50	4.07	512.9	1.11	0.715
Multicrystalline silicon solar cell with a-Si:N:H ARC									
25	14.25	612.4	3.29	0.731	0	12.42	552.6	2.94	0.697
32	13.36	588.8	3.26	0.726	4	11.24	543.4	2.81	0.712
37	13.07	571.1	3.24	0.721	10	9.85	539.4	2.49	0.724
46	12.63	562.3	3.24	0.712	25	8.13	536.7	2.06	0.731
53	12.11	538.5	3.25	0.701	50	5.37	529.3	1.33	0.739

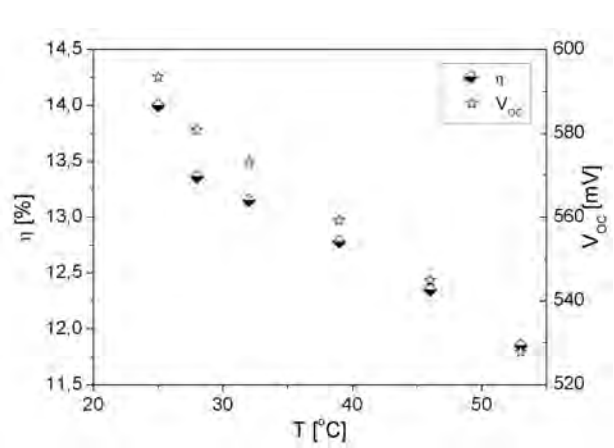

Fig. 4. Dependence of solar cell efficiency and open circuit voltage versus temperature.
Rys. 4. Zależność sprawności ogniw oraz napięcia obwodu otwartego od temperatury.

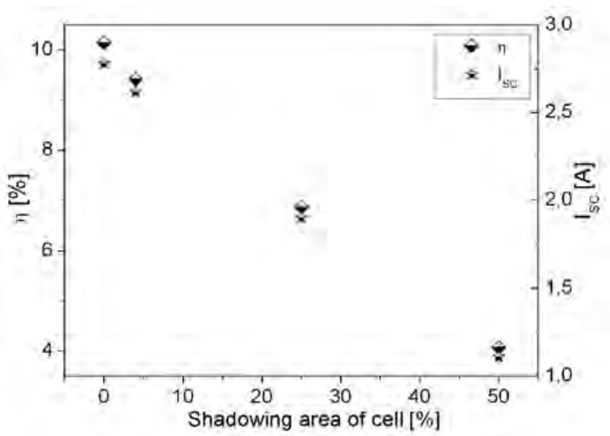

Fig. 5. Dependence of solar cell efficiency and short circuit current versus changeable shadowing area of cell.
Rys. 5. Zależność sprawności ogniw oraz prądu zwarcia od stopnia zacienienia ich powierzchni.

of shadowing on diode current indicates that the operation of solar panels may be disturbed by a single cell behavior in the case of its smaller temporary irradiation in real condition.

4. CONCLUSIONS

Open circuit voltage V_{OC} decreases considerably for temperatures over 35°C which caused that the efficiency also decreases distinctly. Short circuit current I_{SC} rapidly diminishes with increase in shadowing area of cells which leads the decrease in efficiency of solar cells. The similar relationship of solar cell parameters were observed for multicrystalline silicon solar cells with a-Si:N:H and TiO_2 antireflective coatings (Tab. 1). It means that changeable temperature and shadowing area of solar cells have the same influence on their parameters, independently on kind of antireflective coating used. The results indicate that the proper cooling of solar cells is very important. It is also significant to avoid any dirtiness of the surface of panel make act similar to shadowing of solar cells. Another interesting phenomenon is the variation of the shadow during the day on a photovoltaic collector and changes of its parameters.

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REFERENCES

[1] Appelbaum J., Chairt A., Thompson D.: Parameter estimation and screening of solar cells, *Prog. Photovoltaics: Res. Apel.*, 1, (1993), 93 - 106

[2] Chegaar M., Ouennoughi Z., Guechi F., Langueur H.: Determination of solar cells parameters under illuminated conditions, *Journal of Electron Devices*, 2, (2003), 17 - 21

[3] Wójcik P., Pisarkiewicz T., Stapiński T., Lipiński M., Panek P.: Investigation of solar cells under varying illumination, Proc. of XXVI Intern. Conf. of IMAPS – Poland Chapter, Warsaw, 25-27.09.2002, 231 - 234

[4] Swatowska B., Stapiński T., Lipiński M.: Silicon – carbon films for solar cells applications, Proc. of VIII Electron Technology Conference ELTE 2004, Poland, Book of Extended Abstracts, 144

[5] Żdanowicz T., Rodziewicz T., Żabkowska-Wacławek M.: Theoretical analysis of the optimum energy band gap of semiconductors for fabrication of solar cells for applications In higher latitudes locations, *Solar Energy Materials & Solar Cells*, 87, (2005), 757 - 769

[6] Jenkins P.P., Scheiman D.A., Brinker D.J., Appelbaum J.: Low intensity low temperature (LILT) measurements and coefficients on new photovoltaic structures, 25th IEEE Photovoltaic Specialists Conference, Washington D.C., USA, 13-17.05.1996, 317 - 320

[7] Yang E.S.: Fundamentals of semiconductor devices, (1978), 103

[8] Weinstock D., Appelbaum J.: Shadow variation on photovoltaic collectors in a solar field, Proc. of 23rd IEEE Convention of Electrical and Electronics Engineers in Israel, Tel Aviv, 6 - 7.09.2004, 354 - 357

[9] Weinstock D., Appelbaum J.: Optimal solar field design of stationary collectors, *Journal of Solar Energy Engineering*, 126, (2004), 898 - 905

[10] Singh P., Singh S.N., Lal M., Husain M.: Temperature dependence of I-V characteristics and performance parameters of silicon solar cell, *Solar Energy Materials & Solar Cells*, 92, (2008), 1611 - 1616

WPŁYW WARUNKÓW ZEWNĘTRZNYCH NA PARAMETRY KRZEMOWYCH OGNIW SŁONECZNYCH

Praca skupia się na badaniu wpływu zmian temperatury zewnętrznej oraz stopnia zacienienia powierzchni ogniw słonecznych na ich parametry elektryczne. Charakterystyki prądowo-napięciowe I-V ogniw słonecznych na bazie krzemu multikrystalicznego były wyznaczone przy oświetleniu AM 1.5 za pomocą urządzenia sterowanego komputerowo I-V Curve Tracer For Solar Cells Qualification. Poprzez zastosowanie elektrycznego modelu dwudiodowego, pomiary charakterystyk I-V ogniw pozwoliły określić sprawność ogniw oraz ich prąd zwarcia i napięcie obwodu otwartego. Pomiary temperaturowe przeprowadzono w zakresie od 5 do 55°C, przy stałym i równomiernym oświetleniu całej powierzchni ogniw. Zmienny stopień zacienienia powierzchni ogniw miał bardzo istotny wpływ na ich parametry elektryczne. Obniżenie sprawności ogniw słonecznych wraz z temperaturą oraz stopniem zacienienia jest czynnikiem bardzo istotnym przy optymalizacji warunków pracy systemów fotowoltaicznych.

Słowa kluczowe: *krzemowe ogniwo słoneczne, charakterystyka I-V, model dwudiodowy, sprawność ogniwa słonecznego*