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doi:10.15199/48.2018.07.33

Research on the Influence of Environmental Conditions on Electrical Parameters of Interdigitated Back Contact Monocrystalline Silicon Solar Cells

Abstract. *This article presents results of the experiment carried out on the samples of HIT-IBC solar cells. Devices under test have been placed in the climatic chamber in constant ambient temperature from a range (-20 ÷ 100)°C and exposed to irradiation of energy ranging from 700W/m^2 to 1250W/m^2 and spectral composition corresponding to solar spectrum. Measurements of I-V and P-V characteristics have been performed. Results of the analysis have been discussed in the context of photoconversion efficiency in variable irradiation conditions.*

Streszczenie. *Niniejszy artykuł przedstawia wyniki badań ogniw słonecznych typu HIT-IBC. Obiekty badawcze zostały umieszczone w komorze klimatycznej, w stałej temperaturze z zakresu (-20 ÷ 100)°C i poddane działaniu promieniowania świetlnego o energii z zakresu od 700W/m^2 do 1250 W/m^2 i składzie widmowym odpowiadającym promieniowaniu słonecznemu. Przeprowadzono pomiary zależności prądu i mocy w funkcji napięcia ogniwa. Wyniki zostały przeanalizowane w kontekście sprawności konwersji energii słonecznej w warunkach zmiennego nasłonecznienia. (**Badania wpływu warunków środowiskowych na parametry elektryczne ogniw słonecznych typu IBC z krzemu monokrystalicznego**).*

Keywords: HIT-IBC solar cells, silicon, photovoltaics.
Słowa kluczowe: ogniwa słoneczne typu HIT-IBC, krzem, fotowoltaika.

Introduction

Despite the fact that in recent years it is possible to observe dynamic progress in the area of innovative photovoltaic (PV) cells technologies, silicon-based solutions are still dominating in global PV cell production share. According to the forecast presented in [1], such tendency will be preserved until at least 2022, even when the share of all emerging technologies different from crystalline silicon will be compared in total. Considering the field of monocrystalline silicon solar cells, relatively new idea are the interdigitated back contact cells, based on the n-type silicon substrate and heterojunction with intrinsic thin layer, so-called HIT-IBC cells. Rated efficiency of this type of devices reported by National Renewable Energy Laboratory (NREL) [2] has already exceeded 26%, which is one of the best results among all mass-produced types of cells. Distinctive advantage of HIT-IBC structures is the capability to absorb low-energy infrared radiation, what has been confirmed by external quantum efficiency measurements and reported in [3]. Consequently, many issues concerning possible further improvements of the efficiency of HIT-IBC cells are the topics of recent scientific discussions [4-12].

However, as it is known, nominal parameters of PV devices are determined for standard test conditions (STC) that not always correspond to actual environmental conditions, in which solar cells operate. Parameters achieved by PV cells in STC often seem to be inaccurate performance indicator, especially in terms of irradiation level, due to the fact that in certain regions an average solar irradiation is lower or higher than 1000W/m^2. For that reason, it is justified to conduct research aimed at verification of actual electrical parameters of HIT-IBC solar cells operating in conditions of changing irradiance.

This article presents results of the experiment carried out on the samples of HIT-IBC solar cells in order to determine the rate of nominal parameters deterioration for this type of silicon structure, along with decreasing irradiation energy and increasing temperature.

Experiment

Reported research had been carried out on the samples of HIT-IBC solar cell of the area A = 0,015m^2, according to methodology described in [13]. Devices under test were placed in the climatic chamber in precisely controlled environmental conditions such as temperature, humidity and insolation rate. Configuration of the testing circuit enabled to adjust the load of the measured solar cell electronically and record its operating parameters i.e. momentary voltage, current and power. The spectral composition of radiation emitted by the light source matched with solar spectrum and the level of its energy was continuously monitored and recorded. Measurements of I-V and P-V characteristics were performed for certain values of irradiation energy, ranging from 700W/m^2 to 1250W/m^2. During the tests, temperature of the measured cell had been changed in the range (-20 ÷ 100)°C. Tested sample was located in the plane orthogonal to direction of the incident light. Data collected by automated test and acquisition system designed in LabView environment have been discussed in the article in the context of photoconversion efficiency in different irradiation conditions. Dependences prepared for values of irradiation energy different from STC allowed to calculate and compare values of efficiency η and fill factor FF depending on the insolation level. The influence of increasing temperature on electrical parameters of HIT-IBC cells had also been analyzed for different irradiation energies.

Analysis of the obtained results

In order to determine how strong is the influence of changing irradiation conditions on generating capabilities in case of tested HIT-IBC solar cells, at the beginning the I-V (fig.1) and P-V (fig.2) characteristics were plotted for several values of irradiation energy and constant operating temperature 25°C. As it can be seen in figure 1, increase in the irradiation energy value causes significant growth of the cell current across the whole range of the operating voltages. Consequently, location of maximum power point (MPP) shifts towards higher current values. In particular, for irradiation energy E = 700W/m^2 cell current measured for MPP is 4,03A, whereas for E = 1250W/m^2 the value of I_{MPP} increases to 7,47A. On the other hand, the value of cell voltage recorded for MPP is approximately the same independently from changes in irradiation energy and oscillates around U_{MPP} = 0,54V. Similar tendency could be observed for short-circuit current I_{SC} which rises from 4,66A for 700W/m^2 to 8,5A for 1250W/m^2, whereas the open-circuit voltage remains at the same level of U_{OC} = 0,64V.

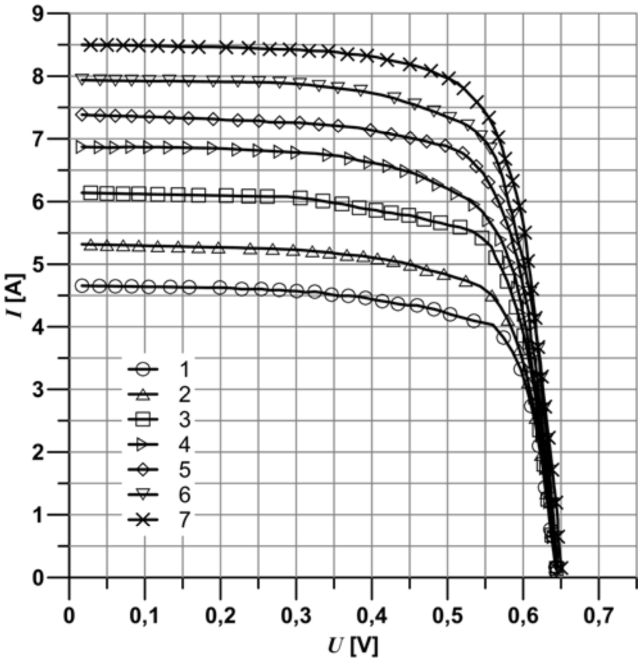

Fig.1. Dependences I = f(U) for sample of HIT-IBC solar cell recorded for operating temperature T = 25°C and different values of irradiation energy E: 1 – 700W/m^2, 2 – 800W/m^2, 3 – 900W/m^2, 4 – 1000W/m^2, 5 – 1100W/m^2, 6 – 1150W/m^2, 7 – 1250W/m^2

Observed tendencies are confirmed by dependences of generated power in the function of cell voltage, plotted for the same conditions and presented in figure 2. As it was shown, maximum output power of the cell increases almost twice from 2,26W for 700W/m^2 to 4,09W for 1250W/m^2, without significant changes in the value of U_{MPP}.

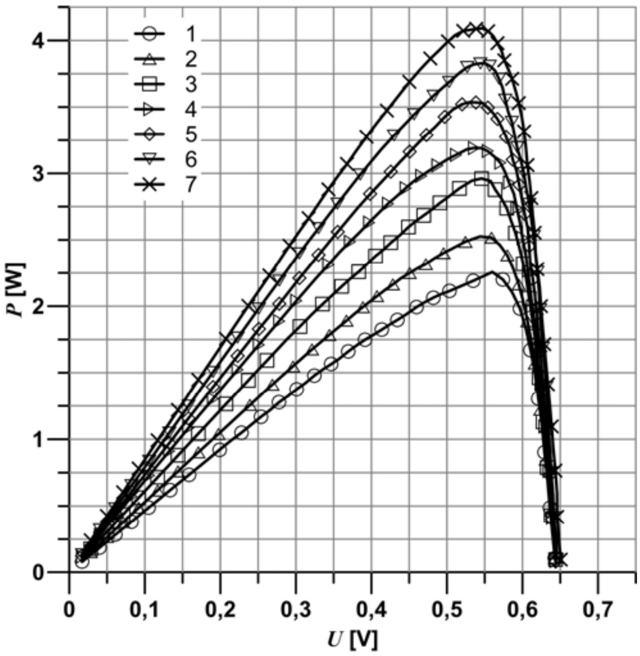

Fig.2. Dependences P = f(U) for sample of HIT-IBC solar cell recorded for operating temperature T = 25°C and different values of irradiation energy E: 1 – 700W/m^2, 2 – 800W/m^2, 3 – 900W/m^2, 4 – 1000W/m^2, 5 – 1100W/m^2, 6 – 1150W/m^2, 7 – 1250W/m^2

Subsequent issue that should be considered discussing the influence of the environmental conditions on electrical parameters of HIT-IBC solar cells is deterioration of those parameters along with increasing temperature. Despite the fact that rising insolation causes considerable growth of generated power, however such situation is also connected with increasing temperature in which considered cell operates. For that reason, the following part of the analysis includes dependences of current (fig.3, fig.5) and power (fig.4, fig.6) in the function of voltage, plotted for different irradiation energies and two cases of temperature: -20°C and 100°C.

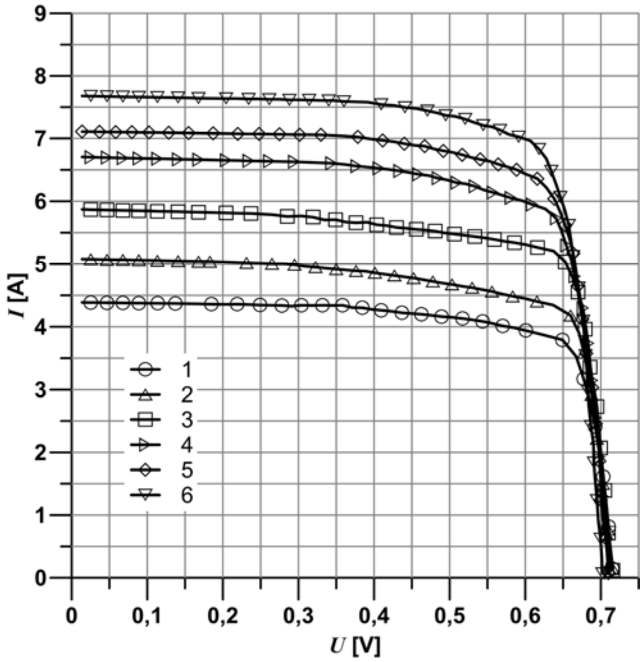

Fig.3. Dependences I = f(U) for sample of HIT-IBC solar cell recorded for operating temperature T = -20°C and different values of irradiation energy E: 1 – 700W/m^2, 2 – 800W/m^2, 3 – 900W/m^2, 4 – 1000W/m^2, 5 – 1100W/m^2, 6 – 1150W/m^2

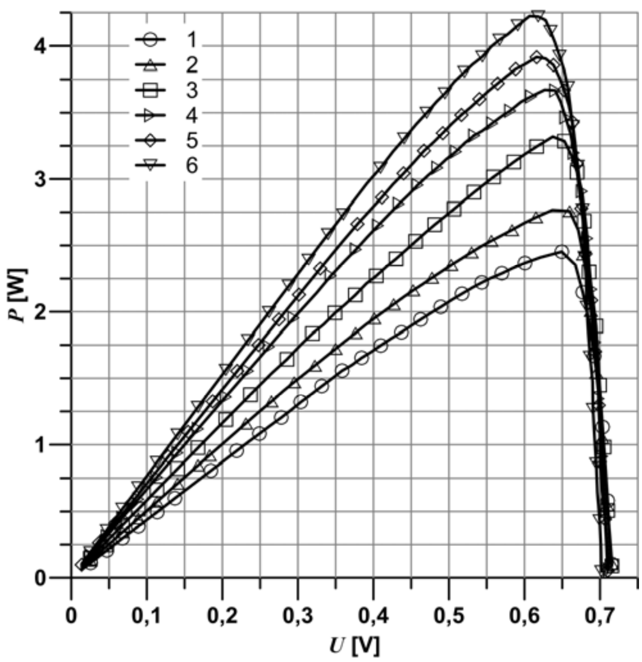

Fig.4. Dependences P = f(U) for sample of HIT-IBC solar cell recorded for operating temperature T = -20°C and different values of irradiation energy E: 1 – 700W/m^2, 2 – 800W/m^2, 3 – 900W/m^2, 4 – 1000W/m^2, 5 – 1100W/m^2, 6 – 1150W/m^2

As it was presented in figure 3, in conditions of lowered temperature tested cell reveals better performance than in STC. Particularly, for all irradiation energies value of U_{OC} raises to 0,71V as well as U_{MPP} increases to 0,63V on average. Similarly as in the case plotted for STC, the cell current grows rapidly with increasing irradiation energy. Especially, for E raising from 700W/m^2 to 1150W/m^2 the value of I_{MPP} changes from 3,79A to 6,96A, whereas the I_{SC} grows from 4,39A to 7,68A. However, in terms of absolute values, considered currents are noticeably lower compared to those recorded for 25°C in whole range of operating voltages. Consequently, despite the fact that that in lowered operating temperature tested cells achieved maximum power for higher U_{MPP} voltages, measured values of P_{MAX} are only slightly higher than those recorded for 25°C, what was shown in figure 4. In particular, the value of P_{MAX} changes from 2,45W for 700W/m^2 to 4,22W for 1250W/m^2.

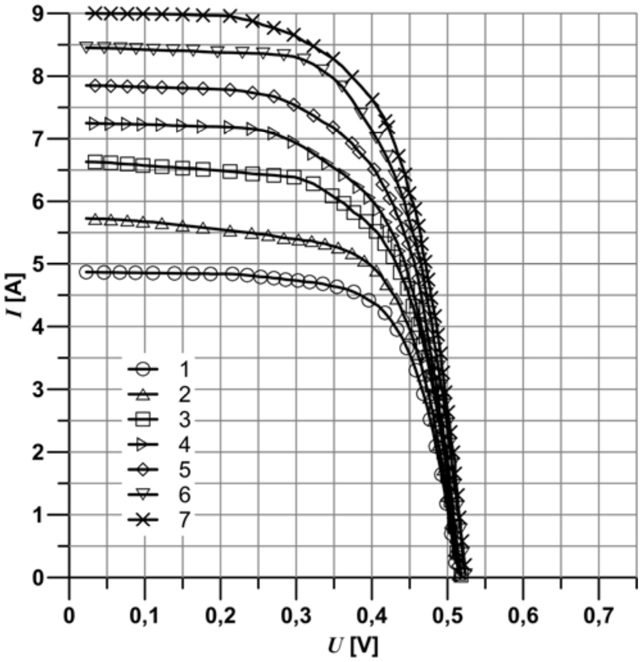

Fig.5. Dependences I = f(U) for sample of HIT-IBC solar cell recorded for operating temperature T = 100°C and different values of irradiation energy E: 1 – 700W/m^2, 2 – 800W/m^2, 3 – 900W/m^2, 4 – 1000W/m^2, 5 – 1100W/m^2, 6 – 1150W/m^2, 7 – 1250W/m^2

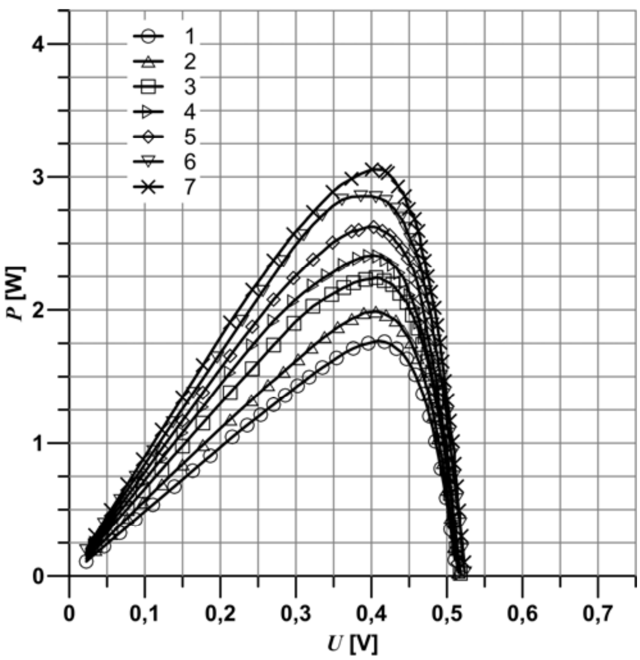

Fig.6. Dependences P = f(U) for sample of HIT-IBC solar cell recorded for operating temperature T = 100°C and different values of irradiation energy E: 1 – 700W/m^2, 2 – 800W/m^2, 3 – 900W/m^2, 4 – 1000W/m^2, 5 – 1100W/m^2, 6 – 1150W/m^2, 7 – 1250W/m^2

In contrast, along with the increasing temperature it is possible to observe significant fall in the value of U_{OC} from 0,64V to 0,52V, irrespective of the irradiation energy (fig.5). Consequently, all characteristics tend to shift towards lower values of the operating voltages, which results in noticeable decrease in maximum output power (fig.6). Slight growth of the cell current could also be observed.

Conclusions

On the basis of the results that had been obtained in the research process it was possible to evaluate the generating capabilities of the HIT-IBC solar cells operating in different environmental conditions, including variable temperature as well as irradiation energy. In order to elaborate objective assessment, for all considered values of irradiation energy and three cases of ambient temperature the efficiency η and the fill factor FF of the tested sample were calculated, according to the following formulas [14]:

(1)
$$\eta = \frac{P_{MAX}}{E \cdot A} \cdot 100$$

where: η – cell conversion efficiency, P_{MAX} – measured maximum power, E – total incident irradiance, A – device area,

(2)
$$FF = \frac{P_{MAX}}{U_{OC} \cdot I_{SC}}$$

where: FF – fill factor, P_{MAX} – measured maximum power, U_{OC} – open-circuit voltage, I_{SC} – short-circuit current.

The results of calculations made for 25°C have been collected in the table 1, whereas corresponding values for the temperatures -20°C and 100°C have been gathered in the table 2 and table 3 respectively.

Table 1. Electrical parameters of measured HIT-IBC cell in the function of irradiation energy E, recorded and calculated for the operating temperature T = 25°C

E [W/m^2]	700	800	900	1000	1100	1150	1250
η [%]	21,0	20,6	21,4	20,8	20,9	21,7	21,3
FF [-]	0,75	0,74	0,75	0,72	0,74	0,75	0,74
P_{MAX} [W]	2,26	2,53	2,96	3,19	3,54	3,83	4,09
I_{SC} [A]	4,66	5,32	6,14	6,87	7,39	7,94	8,50
U_{OC} [V]	0,64	0,64	0,64	0,64	0,64	0,65	0,65

As it can be seen in table 1, if it is assumed that the considered PV cell operates in the constant temperature of 25°C, which is relatively low, there is a direct proportion between the energy of incident light, momentary current of the tested cell and generated peak power. In particular, as the irradiation energy increases by 79%, the maximum power increases by 81%, which is the almost linear dependence for the tested cell. Simultaneously, it is possible to observe the increase in the value of short-circuit current by 82%, whereas the value of open-circuit voltage remains almost unchanged. Furthermore, the values of η and FF also do not reveal tendency to rapid changes along with the raising irradiation energy and stay on the average level of 21% and 0,74 respectively.

Performance indicators of the tested samples slightly improves when the operating temperature falls to -20°C, assuming that irradiation energy remains on the unchanged level, what has been demonstrated in table 2. The most noticeable is the change in the U_{OC} value, that increases with the decrease of temperature independently on the irradiation energy and stabilizes on the average level of 0,71 V. The same tendency reveals such parameters as conversion efficiency η and fill factor FF which average values are equal to 23,4% and 0,78 respectively. Moreover, it is possible to observe that P_{MAX} and I_{SC} values raise across the whole considered range of irradiation energy by 72% and 75% respectively.

Table 2. Electrical parameters of measured HIT-IBC cell in the function of irradiation energy E, recorded and calculated for the operating temperature T = -20°C

E [W/m^2]	700	800	900	1000	1100	1150
η [%]	22,8	22,6	24,0	23,9	23,2	23,9
FF [-]	0,78	0,76	0,79	0,77	0,78	0,78
P_{MAX} [W]	2,45	2,77	3,32	3,67	3,92	4,22
I_{SC} [A]	4,39	5,08	5,87	6,70	7,11	7,68
U_{OC} [V]	0,72	0,72	0,72	0,71	0,71	0,70

However if conditions of higher ambient temperature are considered (table 3), the noticeable degradation of all essential parameters occurs. Likewise in the case of lower temperature, efficiency, fill factor and open-circuit voltage of the tested cell are almost insensitive to the irradiation changes and reach following values on average: η = 16%, FF = 0,66, U_{OC} = 0,52V. Similarly, the values of P_{MAX} and I_{SC} raise along with the increase of E, however the increase rate is different from the case considered in table 1, as P_{MAX} increases by 73% and I_{SC} increases by 85%. Nonetheless, the most distinct tendency is the significant influence of the temperature on the absolute values of measured and calculated parameters.

Table 3. Electrical parameters of measured HIT-IBC cell in the function of irradiation energy E, recorded and calculated for the operating temperature T = 100°C

E [W/m^2]	700	800	900	1000	1100	1150	1250
η [%]	16,5	16,1	16,2	15,7	15,6	16,2	15,9
FF [-]	0,71	0,67	0,65	0,64	0,65	0,65	0,65
P_{MAX} [W]	1,77	1,99	2,24	2,41	2,62	2,85	3,06
I_{SC} [A]	4,87	5,73	6,63	7,25	7,85	8,45	9,00
U_{OC} [V]	0,51	0,52	0,52	0,52	0,51	0,52	0,52

Comparing values in the table 1, table 2 and table 3 it could be seen that regardless of the irradiation energy, along with the temperature increase by 120°C, values of the η and P_{MAX} decrease by approximately 31%, FF decreases by approx. 15%, U_{OC} decreases by approx. 27% and I_{SC} increases by approx. 11%.

Taking above conclusions into consideration it should be underlined that HIT-IBC cells reveal very good performance among all c-Si solar cells, however there are still some issues that could be improved. Therefore, it is justified to conduct subsequent research, directed into developing solutions that ensure further minimization of negative effect of the temperature on the HIT-IBC cells efficiency.

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