Piotr BILLEWICZ

Department of Electrical Devices and High Voltage Technology, Lublin University of Technology

doi:10.15199/48.2018.07.37

Comparative Analysis of the Photovoltaic Cells Efficiency Depending on the Substrate Material Processing Technology

Abstract. *The aim of this article is to present results of the research conducted on the PV cells produced using different technologies. Monocrystalline silicon solar cells of different internal structure were examined using full-spectrum sun simulation system. Analysis included I-V and P-V characteristics as well as calculations of the efficiency and temperature coefficients of the tested cells. Based on the obtained results it was possible to compare performance of the cell produced using ion-implantation technology and the one with substrate treated by diffusion.*

Streszczenie. *Celem artykułu jest zaprezentowanie wyników badań ogniw PV, wykonanych z zastosowaniem różnych technologii produkcji. Ogniwa z krzemu monokrystalicznego, różniące się strukturą wewnętrzną, poddano badaniom z wykorzystaniem systemu do symulacji promieniowania słonecznego o pełnym spektrum, rejestrując charakterystyki I-V oraz P-V badanych próbek. Na podstawie uzyskanych wyników możliwe było porównanie sprawności klasycznych ogniw PV oraz ogniw wyprodukowanych z zastosowaniem implantacji jonowej. (**Analiza porównawcza sprawności ogniw fotowoltaicznych w zależności od technologii wytwarzania materiału podłożowego**).*

Keywords: ion-implantation, solar cells, silicon, photovoltaics.
Słowa kluczowe: implantacja jonowa, ogniwa słoneczne, krzem, fotowoltaika.

Introduction

As it is commonly known, the efficiency of solar energy conversion in crystalline silicon (c-Si) photovoltaic (PV) cells is significantly affected by the series of internal and external factors. Considering internal structure of single PV cell, initial photoelectric effect is finally deteriorated by optical, electrical and quantum losses [1]. Current technical solutions that are applied in order to minimize negative consequences of these losses result in designing new generations of solar cells, which seem to be advanced, multi-layer electronic devices rather than simple p-n junctions. Consequently, some technological processes well known from other branches of electronic industry tends to be successfully adopted for the purposes of PV cells production. One of these methods is ion-implantation technology, introduced in the process of silicon substrate preparation. Application of ion treatment at the early stages of PV cells production has several advantages. It allows to form more complex structures, which are characterized by higher efficiency in standard test conditions (STC) as well as lower sensitivity to thermal conditions [2,3]. What is more, it enables precise and well-controlled doping with simultaneous simplifying the production process [4]. On the other hand, application of the ion-implantation technology generates some new problems and challenges connected with the physical aspects of this process, correlations between implantation parameters, ambient conditions and post-implantation treatment.

Taking above into consideration it is justified to raise the question what are practical benefits of these innovations, compared to previous PV cells generations. The aim of this article is to answer this issue, by discussing results of the research referring to the PV cells made by the means of different technologies.

Experiment

In the scope of this work, monocrystalline silicon solar cells of different internal structure were examined using the methodology described in [5]. Sample number 1 was the conventional single junction cell of the area A_1 = 0,024m^2 and the p-type substrate with n-type layer diffused on. Sample number 2 was the HIT-IBC (heterojunction with intrinsic thin layer and interdigitated back contact) solar cell of the area A_2 = 0,015m^2 and n-type substrate. This type of cell is characterized by additional layer of amorphous silicon and both p$^+$ and n$^+$ regions formed on the rear side of the cell by means of ion implantation.

The main element of the research facility was climatic chamber, equipped with full-spectrum sun simulation system with metal-halide lamp. The testing setup enabled to control environmental conditions such as temperature, relative humidity and solar irradiation. PV cell sample was located inside the climatic chamber on the supporting construction, providing a possibility to adjust the distance from the light source and the angle of inclination. Testing circuit consisted of the examined PV cell, multimeters for voltage and current recording and adjustable load. Light irradiation level was continuously controlled by pyranometer. Testing cycle configuration as well as data acquisition tasks were realized by dedicated application designed in LabView environment. Measurements of I-V and P-V characteristics were performed across the operating temperature range (-20 ÷ 100)°C for irradiation ranging from 750W/m^2 to 1250W/m^2. The following discussion refers to dependences recorded for irradiation energy E = 1000W/m^2 across the whole range of measured temperatures, with respect to the condition that sample is oriented perpendicularly to the incident light.

Analysis of the obtained results

In the first stage of the experimental results analysis, I-V and P-V characteristics were plotted for both tested PV cells operating in the same conditions (fig.1). In order to maintain widely accepted reference point, presented dependences had been recorded in environmental conditions corresponding to STC. As it can be seen, in the same operating conditions the HIT-IBC cell achieves better performance. In particular, it is characterized by higher open-circuit voltage U_{OC} and lower short-circuit current I_{SC}, when compared to the conventional cell. For sample 2 those parameters were equal to 0,64V and 6,87A respectively, whereas corresponding values recorded for sample 1 were 0,56V and 7,89A respectively. Noticeable shift in the values of operating voltages and currents between samples 1 and 2 results in substantially different position of maximum power point (MPP). Sample 1 generates maximum power P_{MAX} = 3,18W for voltage U_{MPP} = 0,44V and current I_{MPP} = 7,23A. Corresponding values recorded for sample 2 are as follows: P_{MAX} = 3,21W, U_{MPP} = 0,54V, I_{MPP} = 5,95A. What needs to be underlined is the fact that both samples achieve similar P_{MAX}, however the area of the sample 2 is about 38% lower than sample 1.

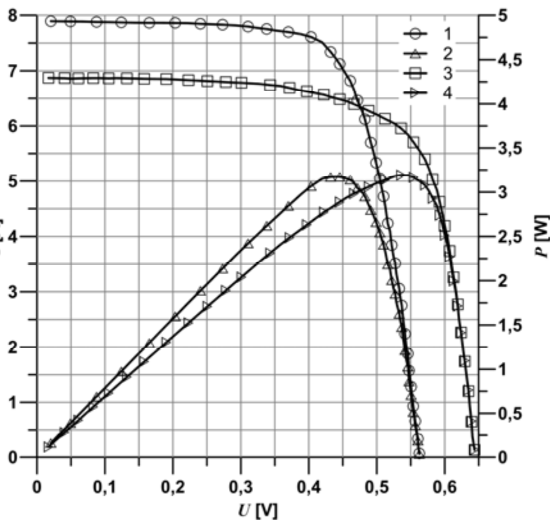

Fig.1. Dependences I = f(U) and P = f(U) for different types of c-Si PV cells (I-V and P-V curves respectively): 1, 2 – conventional cell, 3, 4 – HIT-IBC cell

In order to conduct a detailed research it was necessary to investigate performance of both samples in conditions other than STC. For that reason, in the second stage of the analysis I-V and P-V dependences were plotted for the operating temperature range (-20 ÷ 100)°C. In the figure 2 the I-V characteristics recorded for sample 1 had been presented, whereas figure 3 presents corresponding plots for sample 2.

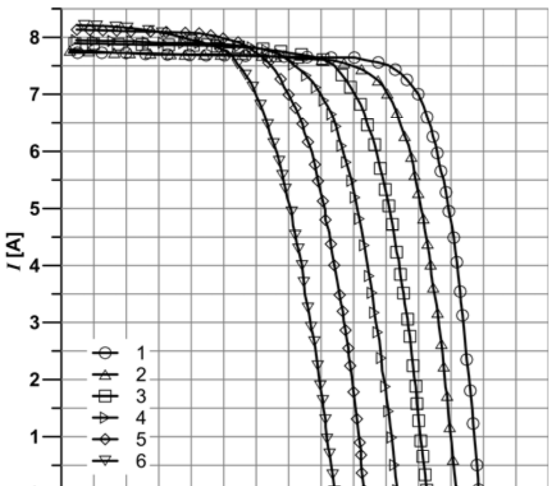

Fig.2. Dependences I = f(U) for sample 1 recorded for different operating temperatures: 1 – -20°C, 2 – 0°C, 3 – 25°C, 4 – 50°C, 5 – 75°C, 6 – 100°C

As it can be seen, in case of both tested samples the correlation between cell performance and temperature has similar character, i.e. as the ambient temperature increases, the I-V curves shift towards lower voltages and higher currents. However, sample 2 tends to operate with higher voltage across the whole temperature range and the temperature coefficient of open-circuit voltage ΔU_{OC} is also lower and equals -0,23%/°C, whereas in case of sample 1 it reaches -0,29%/°C. On the other hand, the output currents of the sample 2 are generally lower and the temperature coefficient of short-circuit current ΔI_{SC} is higher and equals to 0,063%/°C, whereas for the sample 1 it is 0,049%/°C.

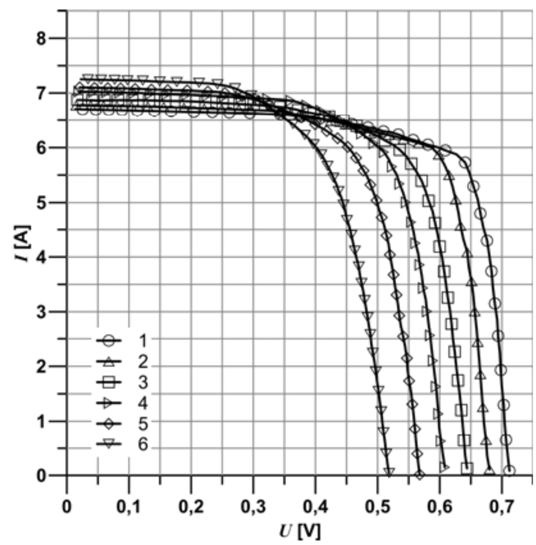

Fig.3. Dependences I = f(U) for sample 2 recorded for different operating temperatures: 1 – -20°C, 2 – 0°C, 3 – 25°C, 4 – 50°C, 5 – 75°C, 6 – 100°C

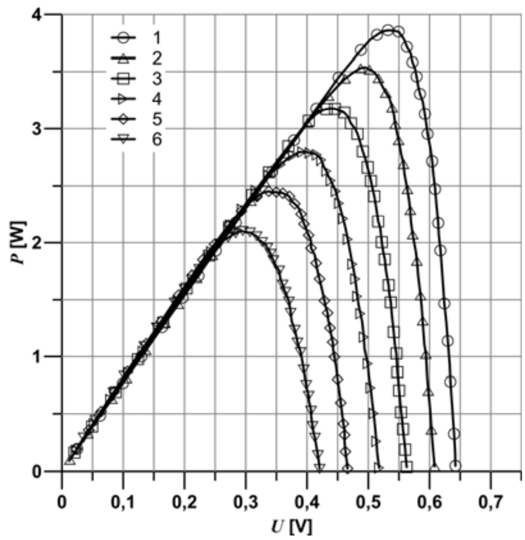

Fig.4. Dependences P = f(U) for sample 1 recorded for different operating temperatures: 1 – -20°C, 2 – 0°C, 3 – 25°C, 4 – 50°C, 5 – 75°C, 6 – 100°C

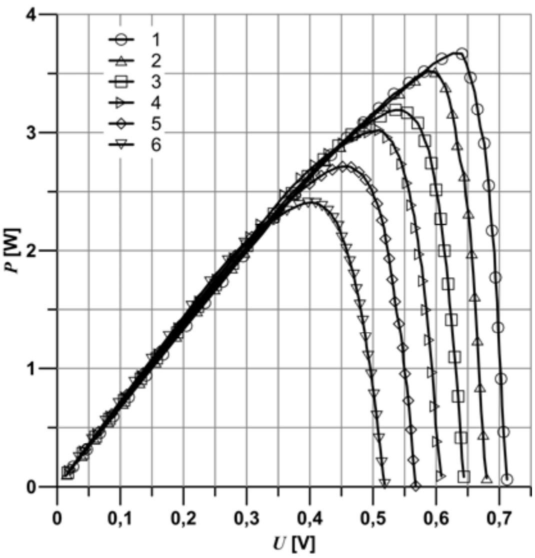

Fig.5. Dependences P = f(U) for sample 2 recorded for different operating temperatures: 1 – -20°C, 2 – 0°C, 3 – 25°C, 4 – 50°C, 5 – 75°C, 6 – 100°C

Above observations do not indicate definitely on the superiority of one of the tested cells over another in the context of variable environmental conditions. Therefore, to evaluate the differences between tested cells correctly it is necessary to compare their P-V characteristics across the considered temperature range (fig.4, fig.5).

Comparison of the plots presented in the figures 4 and 5 clearly shows that sample 2 operates more efficiently in conditions of increasing temperature. As it can be seen, when the ambient temperature does not exceed 25°C, maximum power P_{MAX} generated by both cells is similar or even higher for sample 1. However, when the temperature rises above 25°C it is possible to observe that P_{MAX} for sample 2 is substantially higher than for sample 1 in respective temperatures. This tendency is the reason of significant difference between values of the temperature coefficient of maximum power ΔP_{MAX} calculated for both cells, which equals -0,38%/°C for sample 1 and -0,29%/°C for sample 2.

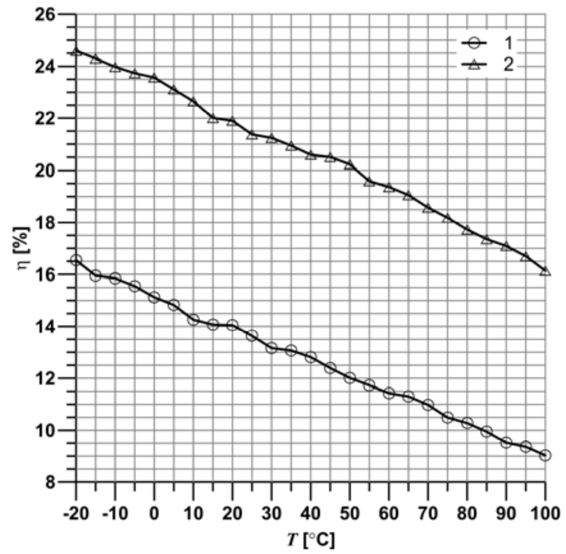

Fig.6. Dependences of the solar cells efficiency η vs. ambient temperature T, recorded for tested samples: 1 – conventional cell (sample 1), 2 – HIT-IBC cell (sample 2)

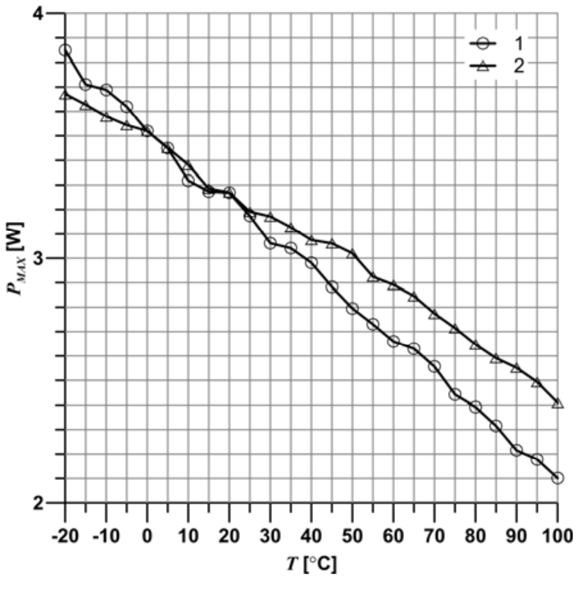

Fig.7. Dependences of the solar cells maximum power P_{MAX} vs. ambient temperature T, recorded for tested samples: 1 – conventional cell (sample 1), 2 – HIT-IBC cell (sample 2)

To summarize results of the analysis presented above, value of tested cells efficiency had been determined for both samples, according to the following formula [6]:

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

where: η – cell conversion efficiency, P_{MAX} – measured maximum power, E – total incident irradiance, A – device area. Calculations that had been carried out covered the range of temperatures for which I-V and P-V characteristics were recorded. The results of this computation had been presented in the figure 6. As it can be seen, calculated efficiency tends to decrease with increasing ambient temperature in case of both tested samples. However, within considered temperature range the efficiency of the sample 2 (HIT-IBC cell) changes from 24,59% to 16,13%, whereas the efficiency of the sample 1 (conventional cell) covers the range from 16,54% to 9,03%.

Next factor that could be used to compare and assess performance of the tested cells from practical point of view is the temperature coefficient of maximum power. As it is known, it indicates the rate of P_{MAX} deterioration along with the increase of temperature. Dynamics of changes in the value of P_{MAX} achieved by both tested cells in certain operating temperatures has been illustrated in the figure 7. As it can be seen, both samples show a tendency to lose generation capabilities along with increasing temperature, however they differ from each other in terms of the pace of changes. It is possible to observe that for temperatures fewer than 25°C sample 1 achieves slightly higher values of P_{MAX}. When the operating temperature oscillates around 25°C generated power is approximately the same for both samples and equals to 3,18W. Subsequently, as the temperature increases the value of P_{MAX} achieved by sample 1 falls significantly faster than in the case of sample 2. Considering the temperatures from 25°C to 100°C value of P_{MAX} for sample 1 decreases from 3,18W to 2,10W, whereas for sample 2 it varies from 3,18W to 2,41W. Across the whole temperature range P_{MAX} for sample 1 falls by 0,015W/°C, whereas for sample 2 by 0,011W/°C.

Conclusions

Based on the obtained results it was possible to compare the performance of the PV cell produced using ion-implantation technology and the one with substrate treated by diffusion. Analysis presented in the article included I-V and P-V dependences of the tested cells for different conditions. Calculations of efficiency as well as observations concerning temperature dependences of MPP for both types of the tested cells have been also discussed.

Taking into account the outcomes of presented analysis it could be concluded that application of ion-implantation technology to produce silicon structures dedicated for PV industry results in growth of PV cells efficiency as well as improvement of the temperature coefficients.

However, as it was shown in [4, 7] there is a necessity of well understanding the correlations between implantation conditions and the properties of the final PV cell. Taking above conclusions into consideration it is justified to conduct subsequent research, directed into development and optimization of ion-implantation technology in the aspect of possible applications in PV cells production process.

Author: *mgr inż. Piotr Billewicz, Politechnika Lubelska, Katedra Urządzeń Elektrycznych i Techniki Wysokich Napięć, ul. Nadbystrzycka 38A, 20-618 Lublin, E-mail: p.billewicz@pollub.pl*

REFERENCES

[1] Lee Y., Park C., Balaji N., Lee Y.J., Dao V.A., High-efficiency Silicon Solar Cells: A Review, *Israel Journal of Chemistry*, 55 (2015), 1050-1063

[2] Lee C.M., Chang S.P., Chang S.J., Wu C.I., Fabrication of High-Efficiency Silicon Solar Cells by Ion Implant Process, *International Journal of Electrochemical Science*, 8 (2013), 7634-7645

[3] Węgierek P., Billewicz P., Research on Thermal Stability of Electrical Parameters of Silicon Used in PV Cells Production Process, *Acta Physica Polonica A*, 128 (2015), n.5, 943-945

[4] Rohatgi A., Meier D.L., McPherson B., Ok Y.W., Upadhyaya A.D., Lai J.H., Zimbardi F., High-Throughput Ion-Implantation for Low-Cost High-Efficiency Silicon Solar Cells, *Energy Procedia*, 15 (2012), 10-19

[5] Billewicz P., Węgierek P., Laboratory Stand for Examining the Influence of Environmental Conditions on Electrical Parameters of Photovoltaic Cells, *Przegląd Elektrotechniczny*, 92 (2016), n.8, 176-179

[6] Luque A., Hegedus S., Handbook of Photovoltaic Science and Engineering, Second Edition, John Wiley & Sons, 2011

[7] Das U.K., Bowden S., Lu M., Burrows M.Z., Jani O., Xu D., Hegedus S.S., Opila R.L., Birkmire R.W., Progress Towards High Efficiency All-Back-Contact Heterojunction c-Si Solar Cells, National Renewable Energy Laboratory (NREL), 2010