DEGRADATION EFFECTS OF THE OUTPUT ELECTRICAL CHARACTERISTICS OF Si SOLAR CELLS AS A RESULT OF IONIZING RADIATION UNDER LOW LIGHT CONDITIONS

by

Nebojša M. STOJANOVIĆ [1], ***Biljana B. SIMIĆ***[1], ***Koviljka Dj. STANKOVIĆ***[1*], ***and Djordje R. LAZAREVIĆ*** [2]

[1]Faculty of Electrical Engineering, University of Belgrade, Serbia
[2] Department of Radiation and Environmental Protection, Vinča Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia

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This paper presents results of radiation resistance of different types of commercially available single- and poly-crystalline silicon solar cells. Sample cells were subjected to gamma radiation from gamma radiation source ^{60}Co. Characteristic parameters of solar cells were extracted from obtained *I-V* curves: open circuit voltage, short circuit current, maximum power point voltage and current, efficiency, fill factor, and series resistance. Obtained results show the level of parameters' degradation with purpose of increasing solar cells applications in radiation environments.

Key words: electrical characteristic, radiation effect, solar cell

INTRODUCTION

In order to produce high efficiency solar cells, photovoltaic (PV) technology is directed, at first, to investigation of fundamental cell's parameters (such as life time of charge carriers, their transport processes, generation and annihilation of electron-hole pairs, internal series and parallel resistance, *etc*.) caused by impurities, defects, and dopants during the solar cells manufacturing [1-4]. Relationship between fundamental parameters and output characteristics (open circuit voltage, short circuit current density, output power in maximum power point, voltage in maximum power point, current in maximum power point, fill factor, and efficiency) is the most important stage while investigating operating performance of solar cells.

PV solar cells are often exposed to radiation during exploitation. Since their working conditions usually do not allow regular maintenance, stability of their output electrical characteristics is very important. Therefore, investigation of radiation resistance of solar cells is interesting not only for prediction of solar cells operating lifetime and their end-of-life characteristics, but also for improvements in design of solar cells intended for use in hostile working conditions, such as radiation environment [5-7].

* Corresponding author; e-mail: kstankovic@etf.rs

The aim of this paper is to investigate the radiation resistance of different types of commercially available single-crystalline and poly-crystalline silicon solar cells. Samples were subjected to gamma radiation from ^{60}Co source and received a few different dose levels. Output parameters of solar cells were extracted from recorded *I-V* curves, including: open circuit voltage, short circuit current, efficiency, fill factor, and series resistance.

EXPERIMENT

Experimental work was based on recording *I-V* characteristics of solar cells, varying measurements parameters: solar cell type, light intensity, and radiation dose. *I-V* curves represent the basic and most common way to obtain, in a fast and simple way, variety of data related both to output and to fundamental parameters of solar cells. Samples marked S_1 and S_2 are single-crystalline silicone solar cells while sample P_1 is poly-crystalline silicone solar cell. Light intensity was varied by changing the distance of sample cells from the light source, and was controlled by using a calibrated standard cell and lux-meter Laybold (sensor $F = 0.76$). Values of light flux used during the experiment were of 32 W/m^2 and 58 W/m^2 for single-crystalline silicone solar cells and 101 W/m^2 and 338 W/m^2 for poly-crystalline silicone solar cell.

Temperature of the sample was monitored by thermocouple and voltage and current measurements were performed by Metron M890C digital multi-meters. Irradiation of samples was carried out in ^{60}Co gamma radiation field with doses ranging from 10 Gy to 4353 kGy. *I-V* curves were recorded before initial irradiation, and after each irradiation step.

All measurements were performed under stable conditions. The expanded combined uncertainty of each procedure did not exceed 5 % [8, 9].

Parameters observed before and after irradiation were: open circuit voltage (V_{oc}), short circuit current density (J_{sc}), internal series resistance (R_s), output power in maximum power point (P_{mpp}), voltage in maximum power point (V_{mpp}), current in maximum power point (J_{mpp}), fill factor (FF), and efficiency (η).

RESULTS AND DISCUSSIONS

Results of the observed parameters for single-crystalline silicone solar cells before irradiation and after receiving cumulative doses of 10, 110, and 490 Gy, under light flux of 32 W/m^2 and 58 W/m^2 (white light) for samples S_1 and S_2 are given in tabs. 1 and 2, respectively.

Table 3 shows results obtained for sample P_1, before irradiation and after receiving cumulative doses of 905 kGy and 5258 kGy, under light flux of 101 W/m^2 and 338 W/m^2.

Obtained results for single-crystalline (S_1 and S_2) and poly-crystalline (P_1) silicon solar cells show the output electrical characteristics in hostile working conditions (reduced light intensity and presence of

Table 1. Measured parameters of sample S_1 before irradiation and after receiving cumulative doses of 10, 110, and 490 Gy, under light flux of 32 W/m^2 and 58 W/m^2

Flux [Wm^{-2}]	32				58			
Dose [Gy]	0	10	110	490	0	10	110	490
V_{oc} [mV]	409	412	396	398	409	412	396	398
J_{sc} [mAcm^{-2}]	0.897	0.896	0.932	0.913	1.686	1.735	1.577	1.493
R_s [ ]	5.59	7.57	8.00	7.24	5.59	7.57	8.00	7.24
P_{mpp} [Wm^{-2}]	2.313	2.206	2.117	2.152	4.970	5.253	4.521	4.238
V_{mpp} [mV]	325.98	324.34	312.16	296.84	366.52	370.29	358.47	349.21
J_{mpp} [mAcm^{-2}]	0.710	0.680	0.678	0.725	1.356	1.419	1.261	1.214
FF	0.630	0.598	0.573	0.592	0.652	0.659	0.638	0.638
η [%]	7.198	6.867	6.598	6.696	8.533	9.019	7.761	7.267

Table 2. Measured parameters of sample S_2 before irradiation and after receiving cumulative doses of 10, 110, and 490 Gy, under light flux of 32 W/m^2 and 58 W/m^2

Flux [Wm^{-2}]	32			58		
Dose [Gy]	0	10	238	0	10	238
V_{oc} [mV]	447	444	391	476	477	432
J_{sc} [mAcm^{-2}]	0.973	0.956	0.756	1.789	1.658	1.311
R_s [ ]	3.63	4.2	5.72	1.76	2.27	3.22
P_{mpp} [Wm^{-2}]	2.967	2.804	1.893	6.099	5.281	3.682
V_{mpp} [mV]	359.63	356.33	302.17	399.54	396.67	342.79
J_{mpp} [mAcm^{-2}]	0.825	0.787	0.627	1.526	1.331	1.074
FF	0.683	0.660	0.632	0.716	0.668	0.650
η [%]	9.23	8.73	5.89	10.47	9.07	6.32

Table 3. Measured parameters of sample P_1 before irradiation and after receiving cumulative doses of 905 Gy and 5258 Gy, under light flux of 101 W/m^2 and 338 W/m^2

Flux [Wm^{-2}]	101			338		
Dose [Gy]	0	905	5258	0	905	5258
V_{oc} [mV]	424	356	348	477	421	387
J_{sc} [mAcm^{-2}]	1.906	1.353	1.074	6.820	4.638	4.085
R_s [ ]	4.14	5.02	5.33	0.76	1.15	1.13
P_{mpp} [Wm^{-2}]	4.853	3.249	2.352	23.080	12.931	10.854
V_{mpp} [mV]	319.82	248.04	256.57	389.89	341.75	330.34
J_{mpp} [mAcm^{-2}]	1.518	1.310	0.917	5.920	3.784	3.286
FF	0.600	0.659	0.630	0.709	0.663	0.687
η [%]	4.81	3.22	2.33	6.82	3.82	3.21

ionizing radiation). Variations of these parameters are shown in respect both to light flux and to received radiation doses.

There are three typical zones of accumulated radiation doses that can be distinguished regarding the solar cells level of degradation: small, medium and high doses. At the level of small doses, solar cells did not show significant changes in output characteristics, while at the level of medium doses samples showed significant degradation of output characteristics. Finally, at high doses level, solar cells showed reduced degradation compared to trends displayed on lower doses.

All the examined characteristics showed degradation with increased doses of gamma radiation, except for fill factor values, which showed relatively steady values.

In addition, different types of solar cells exposed to similar doses of radiation showed different levels of change. With respect to total doses of gamma radiation, short circuit currents have dropped to 45 %-50 % of initial values with single-crystalline, and to 40 %-60 % with poly-crystalline samples. Open circuit voltage dropped to 81 %- 83 % with single- crystalline and to 75 %-82 % with poly-crystalline cells, and the efficiency dropped to 36 %-42 % of initial values for single- crystalline and 23 %-47 % for poly-crystalline cells. This result is useful for determination of the quality of solar cells.

CONCLUSIONS

All the examined radiation resistance characteristics of commercially available single-crystalline and poly-crystalline silicon solar cells showed degradation with increased doses of gamma radiation, except for fill factor values, which showed relatively steady values. With respect to total doses of gamma radiation, short circuit currents have dropped to 45 %-50 % of initial values with single-crystalline, and to 40 %-60 % with poly-crystalline samples. Open circuit voltage dropped to 81 %-83 % with single- and to 75 %-82 % with poly-crystalline cells, and the efficiency dropped to 36 %-42 % of initial values for single- and 23 %-47 % for poly-crystalline cells.

Results presented in this paper provide useful data related to degradation effects of radiation on output electrical characteristics of silicone solar cells, thus enabling prediction of behavior of solar cells exposed to increased levels of radiation and possible estimation of their operating lifetime.

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AUTHOR CONTRIBUTIONS

Theoretical analysis was carried out by N. M. Stojanović, B. B. Simić, and K. Dj. Stanković. Experiments were carried out by B. B. Simić and Dj. R. Lazarević. All of the authors have analysed and discussed the results. The manuscript was written by N. M. Stojanović and B. B. Simić. The tables were prepared by N. M. Stojanović.

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**Небојша М. СТОЈАНОВИЋ, Биљана Б. СИМИЋ,
Ковиљка Ђ. СТАНКОВИЋ, Ђорђе Р. ЛАЗАРЕВИЋ**

ЕФЕКТИ ДЕГРАДАЦИЈЕ ИЗЛАЗНИХ ЕЛЕКТРИЧНИХ ОСОБИНА Si СОЛАРНИХ ЋЕЛИЈА КАО РЕЗУЛТАТ ЈОНИЗУЈУЋЕГ ЗРАЧЕЊА У УСЛОВИМА НИСКОГ ОСВЕТЉАВАЊА

У раду су приказани резултати истраживања радијационе отпорности различитих типова комерцијално доступних монокристалних и поликристалних силицијумских соларних ћелија. Узорци ћелија подвргнути су гама зрачењу из извора ^{60}Co. Карактеристични параметри соларних ћелија изведени су из добијених *I-V* кривих: напон отвореног кола, струја кратког споја, тачка максималног напона и струје, ефикасност, фактор испуне и серијска отпорност. Добијени резултати приказују ниво деградације параметара силицијумских соларних ћелија, у циљу повећања њихове примене у условима зрачења.

Кључне речи: електрична карактеристика, ефекат зрачења, соларна ћелија