STABILITY OF ELECTRIC CHARACTERISTICS OF SOLAR CELLS FOR CONTINUOUS POWER SUPPLY

by

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Scientific paper
DOI: 10.2298/NTRP1504306S

This paper investigates the output characteristics of photovoltaic solar cells working in hostile working conditions. Examined cells, produced by different innovative procedures, are available in the market. The goal was to investigate stability of electric characteristics of solar cells, which are used today in photovoltaic solar modules for charging rechargeable batteries which, coupled with batteries, supply various electronic systems such as radio repeaters on mountains tops, airplanes, mobile communication stations and other remote facilities. Charging of rechargeable batteries requires up to 25 % higher voltage compared to nominal output voltage of the battery. This paper presents results of research of solar cells, which also apply to cases in which continuous power supply is required.

Key words: solar cell, electric characteristic, neutron radiation, gamma radiation

INTRODUCTION

Today's fast technological advancement relies on development of electronic components. Great advancements were achieved in miniaturization of electronic devices turned into integrated circuits [1-6]. These devices tend to have a lower power requirement, which enables use of power supplies of lower outputs, such as photovoltaic (solar) cells and modules. This has enabled wider use of photovoltaic (PV) solar cells in power supplies. PV solar cells are often exposed to various forms of radiation (*e. g.* on satellites or spacecrafts, as well as in installations and systems in inaccessible places and locations affected by natural disasters). Therefore, extensive researches are conducted with the goal to study the influence of radiation to solar cells characteristics [6-12], as well as with the goal to develop solar cells that have greater resistance to radiation [13-15], *i. e*., where the influence of radiation to output characteristics is less expressed. Researchers presented in this paper take into account another unfavorable influence, the reduced insolation of cells.

Methods used for investigation of solar cells stability during their exploitation consisted of recording the current-voltage (I-V) characteristics of solar cells, with variation of following parameters: solar cell type, illumination intensity, type of radiation, energy and dose of radiation. Measurements have been conducted with and without presence of radiation source. Influence of neutron and gamma radiation intensity on the degradation level of silicon solar cells characteristics was analyzed on reduced level of cells illumination. Degradation of the solar cells open circuit voltage in the radiation field was analyzed separately, since it is extremely important for providing continuous power supply for both the backup rechargeable (ACCU) batteries and electronic and electric devices.

DEGRADING EFFECT OF NEUTRON RADIATION TO SI SOLAR CELLS

Neutron radiation is one of the main reasons for radiation damage of electronic systems in general. Since neutrons are relatively heavy electrically neutral particles (1840 times heavier than electrons), instead to ionize atoms or molecules, they collide with atoms from semiconductor lattice, so that they displace or move the whole atoms from their locations within the lattice and such atoms take interstitial positions within the crystal. This leads to the disarrangement or the cur-

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vature of the lattice's local structure. The initial place where the atom was located is called vacancy. The moved atom is called interstitial atom and the pair interstitial-vacancy is called Frenkel defect [1-3].

If the energy of the incident neutron is high enough, such neutron may transfer enough energy to the atom that it displaced from the lattice, so that this atom may displace other atoms from the lattice. With high-energy neutrons, such phenomenon may continue in cascades and form defects within the lattice structure.

Finally, all the moved atoms loose energy until thermal balance in the lattice is accomplished. Some of these atoms come to the locations of isolated vacancies, and that re-establishes the local structure of the lattice. Some of the atoms are combined with doped atoms or atoms of impurities and form stable defects. These defects are electrically inactive, so that they do not represent recombination centers or *traps.* However, mobile vacancies may be combined with atoms of impurities, donor atoms or other present vacancies, so that they may create temperature stable defects. Such defects, called the defective complexes, represent effective recombination centers or *traps* leading to change of resistance [4, 5].

Before they become the participants in formation of defective complexes, vacancies are mobile and represent a good recombination potential for catching minority carriers. During a very short period after the beginning of neutron impulse, such vacancies are to a great extent responsible for significant reduction of the life period of minority carriers. This effect decelerates fast due to the recovery happening within the material, so that this parameter reaches its asymptotic, reduced value very fast.

EXPERIMENTAL WORK

Experimental part of this work is based on recording current-voltage (I-V) characteristics of solar cells, with variation of measuring parameters: solar cell type, illumination type, illumination intensity, radioactive radiation type, energy and dose of radioactive radiation. Silicon solar cells on the basis of mono-crystal and poly-crystal silicon have been used in the experimental measurements. Mono-crystal silicon samples have been designated with E4 and D4, while poly-crystal silicon samples have been designated with A, D2, and F3. Samples were subjected to the action of radioactive radiation in the form of point source of neutrons and the source of gamma radiation (^{60}Co).

Point source of neutrons Pu-Be was used as the source of neutron radiation [16]. A configuration was used in which the samples were in direct contact with neutron source, while the maximum dose rate accomplished was d*D*/d*t* = 0.36 mGy/h. Measurement of the intensity of neutron radiation equivalent dose were performed by Dineutron device of the French company Nardeux. Samples subjected to neutron radiation absorbed the dose up to 200 mGy.

Two ^{60}Co sources were used as the source of gamma radiation. Absorbed dose of mono-crystal silicon samples ranged up to 490 Gy, while the absorbed dose of poly-crystal silicon samples ranged up to 5825 Gy.

All measurements were performed under well-defined conditions. Level of illumination was regulated by the distance from the source and controlled during measurement by calibrated standard cell and LEYBOLD lux-meter (sensor *F* = 0.76). Sample temperature was regulated by thermocouple. Measurements of voltage and output current were conducted by analogue multi-meter Iskra Ml 7045 and digital multi-meter Metron M890C.

MEASUREMENTS OF CURRENT-VOLTAGE CHARACTERISTICS

Current-voltage (I-V) characteristics of solar cells represent the basic and the most often used method for characterization of solar cells. I-V characteristics enable fast and simple way to obtain a great number of data regarding both output and fundamental parameters of solar cells.

Cell surfaces vary both at different types of used cells and within the same type (group) of samples, so that all the values of currents at I-V curves are scaled to unit surface, *i. e.*, these are presented in the form of surface current density *J*.

Standard measuring configuration was used for measurement of I-V curves. I-V curves were recorded at different levels of illumination (between 30 W/m^2 and 350 W/m^2). I-V characteristics were recorded at white light and monochromatic light (sodium SOX lamp under low pressure). All I-V measurements were performed before the first irradiation and right after each irradiation step.

Analysis of the measurement results is given through the analysis of influences of various types of radioactive radiation on output characteristics of solar cells.

RESULTS OF MEASUREMENTS AND ANALYSIS

The results – parameters of solar cells before and after the radiation by gamma and neutron source are given in subsequent sections. Results present dependencies of series resistance R_s, open-circuit voltage V_{oc} and short-circuit current density J_{sc} on received radiation doses. Results were obtained under different illumination levels.

Samples subjected to neutron radiation

Characteristics of series resistance depending on the received dose of neutron radiation for the samples E4 and D4 are shown in figs. 1 and 2, at three and two levels of cell illumination, respectively. Increase of the

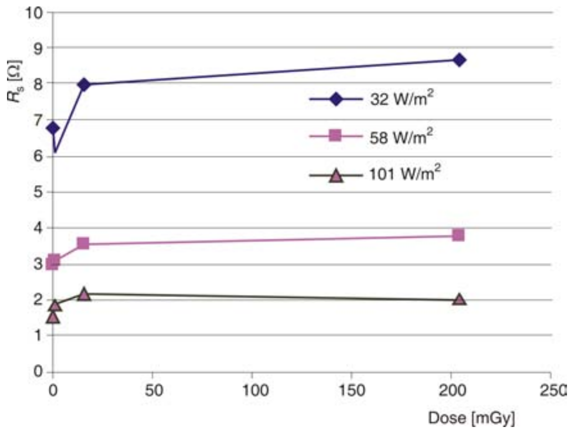

Figure 1. Series resistance *vs.* received dose of neutron radiation for sample E4

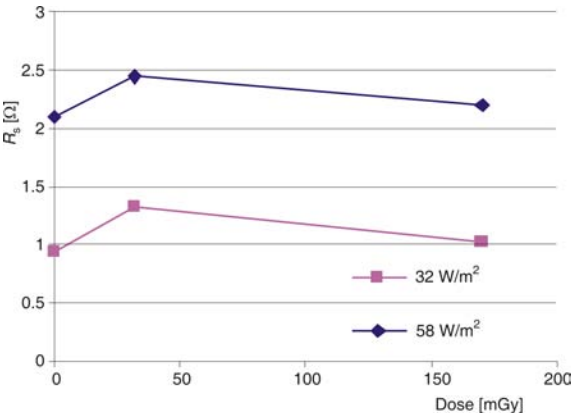

Figure 2. Series resistance *vs.* received dose of neutron radiation for sample D4

value of series resistance is obvious for the sample E4 with lower received doses, while with higher doses the value is practically constant, at lower levels of illumination. On sample D4, reduction of the value of series resistance is noticed after the initial increase. Such behavior indicates that the maximum concentration of defective conditions has been reached.

Characteristics of open circuit voltage V_{oc} dependence on the received dose of neutron radiation for the samples E4 and D4, respectively, at two levels of illumination, are depicted in the figs. 3 and 4. Very small drop of the V_{oc} value is characteristic tor these samples.

Samples subjected to gamma radiation

Characteristics of the short circuit current density J_{sc} *vs*. received dose of gamma radiation for the sample E2, at two levels of illumination, are plotted in fig. 5. Changes of values for J_{sc} are not consistent or expressed significantly.

In fig. 6, dependence of the open circuit voltage on the received dose of gamma radiation for the sample E2, at two levels of illumination, is presented. A

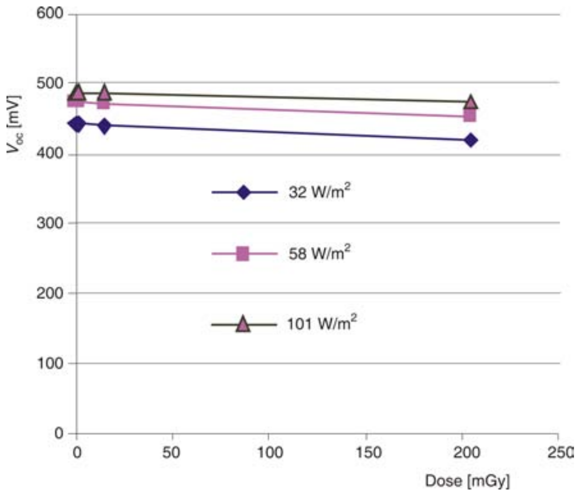

Figure 3. Open circuit voltage *vs.* received dose of neutron radiation for sample E4

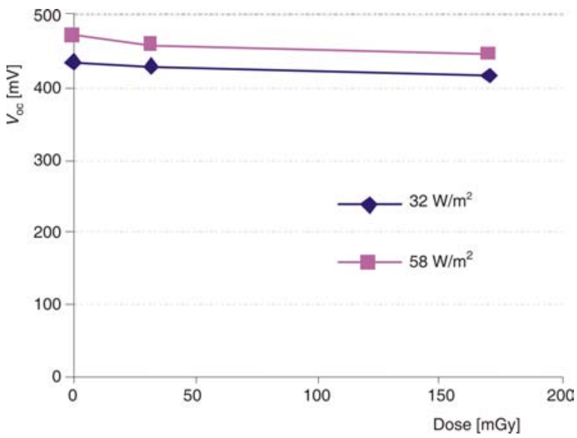

Figure 4. Open circuit voltage *vs.* received dose of neutron radiation for sample D4

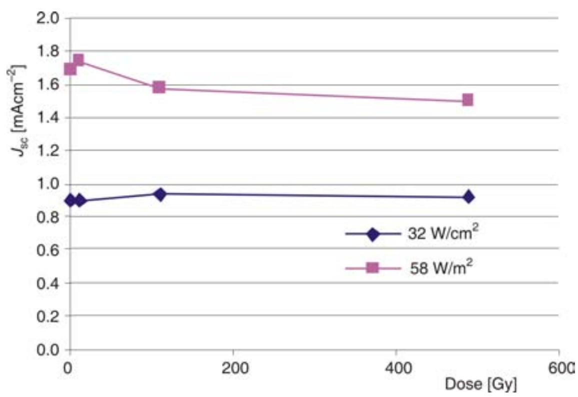

Figure 5. Short circuit current density *vs.* received dose of gamma radiation for sample E2

small increase is noticed after received cumulative doses of 10 Gy and 100 Gy, then a drop of value for V_{oc}, and after the next step of radiation there were no changes of V_{oc} values.

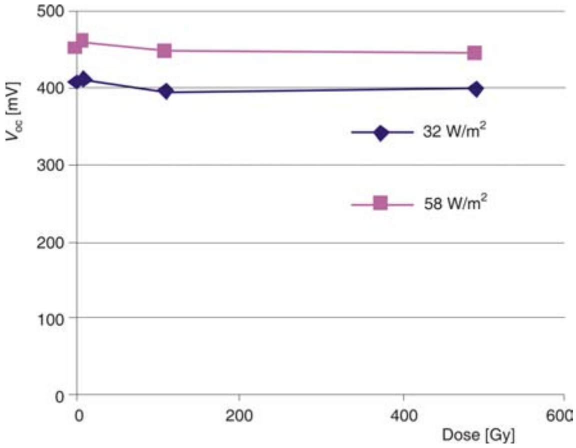

Figure 6. Open circuit voltage *vs*. received dose of gamma radiation for sample E2

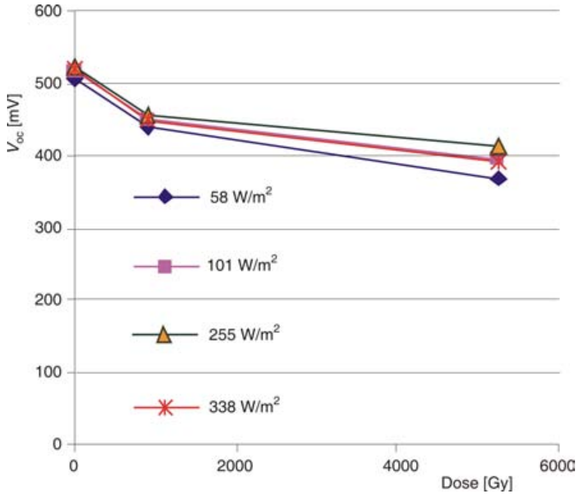

Figure 7. Open circuit voltage *vs*. received dose of gamma radiation for sample A

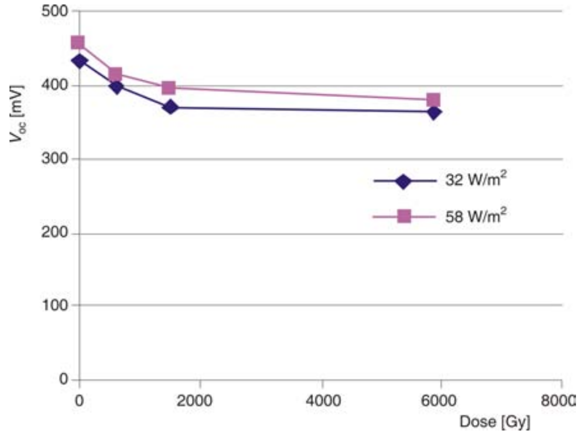

Figure 8. Open circuit voltage *vs*. received dose of gamma radiation for sample D2

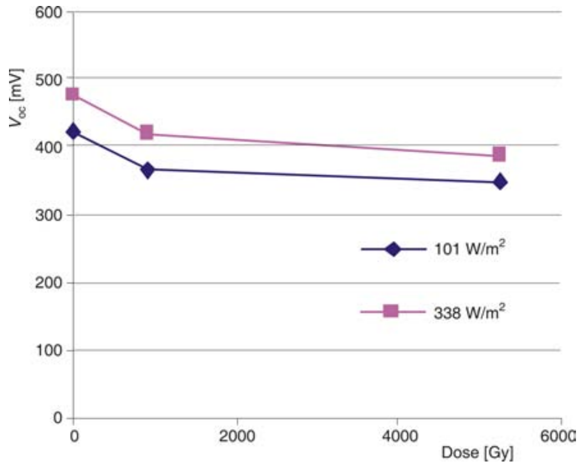

Figure 9. Open circuit voltage *vs*. received dose of gamma radiation for sample F3

Characteristics of the open circuit voltage depending on the received dose of gamma radiation for the sample A, at four levels of illumination, are plotted in the fig. 7. As in the previous two cases, there is a sharp drop of V_{oc} value after the first step of radiation and less significant drop of V_{oc} value after the second step of radiation.

Characteristics of the open circuit voltage *vs*. received dose of gamma radiation for the samples D2 and F3, respectively, at two levels of cell illumination, are depicted in figs. 8 and 9. An initial sharp drop of V_{oc} value is noticed with these samples also, as well as less significant drop of V_{oc} value after the last step of radiation.

CONCLUSIONS

Research described in this paper was focused on studying radiation influences to changes of output electrical characteristics of solar cells (open circuit voltage V_{oc}, short circuit current density J_{sc} and series resistance R_s) in conditions of poor insolation, on silicon solar cells that are available in the market. Experimental work consisted of the preparation of samples from available cells, their sorting and measuring of I-V characteristics with the most important parameters of cells that were the subject of the research. The goal of measuring was to test stability of output electrical characteristics of solar cells. Since there is a great innovative technological competition in this field today (there are more than 20 different innovative approaches with equal chances in the future market), these results are important also for evaluation of the quality of used solar cells. Regarding the application of PV solar devices, these are very important, especially for application of solar cells in devices and systems at locations with difficult working conditions. It refers primarily to the presence of radioactive radiation and poor insolation, especially in accidental conditions when it is necessary to provide the required electrical power supply for telecommunication systems, illumination and others. The results of this paper show that the technological level of used solar cells is such that they are able to provide charging current for ACCU batteries with which they are coupled for continual operation, if the charging system is designed according to the behavior of the open circuit voltage V_{oc} that is graphically presented here.

ACKNOWLEDGEMENT

The Ministry of Education, Science and Technological Development of the Republic of Serbia supported this work under Contract III 171007.

AUTHORS' CONTRIBUTIONS

All authors performed theoretical analysis. Experiments were carried out by N. M. Stojanović and Dj. R. Lazarević. Literature research was carried out and manuscript was written by all authors. The figures were prepared by T. M. Stojić. All authors analyzed and discussed the results.

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Received on September 21, 2015
Accepted on October 26, 2015

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СТАБИЛНОСТ КАРАКТЕРИСТИКА СОЛАРНИХ ЋЕЛИЈА ЗА КОНТИНУАЛНО НАПАЈАЊЕ

У раду се разматрају излазне карактеристике фотонапонских соларних ћелија у условима рада у пољима нуклеарног зрачења. Ћелије коришћене у експерименту биле су комерцијалне, произведене од различитих произвођача. Циљ рада је било испитивање стабилности електричних карактеристика које се користе као соларни (фотонапонски) модули за пуњење акумулатора, који формирају изворе напајања за различите системе као што су радиооператори, репетитори, мобилне комуникације и слично.

Кључне речи: соларна ћелија, електрична карактеристика, неутронско зрачење, гама зрачење