SUCCESSIVE NEUTRON AND GAMMA IRRADIATION AND THEIR IMPACT ON THE CHARACTERISTICS OF SOLAR CELLS

by

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This study investigates the effects of successive neutron and gamma radiation on the parameters of commercial solar cells. Several solar panels have been exposed to neutron radiation and then, after 30 days of recovery, to gamma radiation. A series of measurements of solar cell parameters have been undertaken to determine the reliability of solar cells in the condition of successive irradiation of different types of rays. Solar cell parameters have been measured before and after every step of irradiation. The process of annealing has also been observed. This paper aims to present the effects of both neutron and gamma radiation on the same solar cell sample.

Key words: solar panel, gamma irradiation, neutron irradiation, I-V characteristic, series resistance, parallel resistance, open-circuit voltage, short-circuit current

INTRODUCTION

Nowadays, energy consumption is very high. Almost every area of human life requires energy. Most of the energy is used for transport, heating, cooling, and generation of electricity. One kind of energy that had an exceptional expansion in the last decades is solar energy. Applications of photovoltaic (PV) conversion of solar energy and solar systems based on it are countless. Solar energy is one of the most acceptable sources of electrical energy and because of that, solar systems are not very expensive which is their main advantage. The basic unit of solar systems is the solar cell which belongs to semiconductor detector devices. The possibilities of application of solar cells are very wide: communications, signal processing, photonic sensing, some special applications, *etc*. However, PV technology and systems also have some disadvantages and limitations, like low efficiency and sensitivity to external influences, especially radiation. A number of researchers and institutions work on the development of solar cells, and try to improve the conventional solar cell characteristics based on semiconductor materials and explore the possibilities of using new materials [1].

The main reason for the production of new and improved existing solar cells is the intention to make them reliable and effective in specific circumstances, like space [2-4]. In various work conditions, solar cells could work in presence of different types of radiation, like neutrons, gamma rays, alpha particles, electrons, protons, positrons, and heavy ions. Considering the conditions in space (vacuum, gas), it would be interesting to investigate whether exposure to radiation will change the characteristics of solar cells so much that they start to behave like electrodes in a vacuum and cause an eventual breakdown between those located at a small distance. There has been a lot of research on the conditions under which a breakdown occurs between electrodes in vacuum or gas [5-11].

This work describes a series of measurements undertaken to try to identify the changes in the behaviour of solar cells exposed to successive neutron and gamma irradiation.

EXPERIMENTAL PROCEDURE

Solar cells used in this study are commercially available monocrystalline silicon solar panels. Their basic characteristics are a maximum power voltage of 4.0 V, maximum power current of 100.0 mA, and dimension: 70 mm 65 mm 3.2 mm.

Devices were first exposed to neutron and gamma radiation from a ^{241}Am-Be source and then, after one month, to a ^{60}Co gamma source. Both sources were housed in the Vinča Institute of Nuclear Sciences in Belgrade, Serbia.

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The ^{241}Am-Be source emits gamma photons of low energy (60 keV and 14 keV) with the activity of 3.7 10^{10} Bq, the intensity of the neutron emission of 2.7 10^6 s^{-1} and the mean energy of the neutrons E_{nav} = = 5.5 MeV. The panels were placed at a distance of 5 cm from the source, so the photon equivalent dose rate is $\dot{H}_\gamma$ = 12 mSvh^{-1}, and the photon absorbed dose rate is $\dot{D}_\gamma$ = 12 mSvh^{-1}. The calculated neutron absorbed dose rate is $\dot{D}_n$ = 1.714 mSvh^{-1} and the equivalent dose rate of neutrons is $\dot{H}_n$ = 12 mSvh^{-1} with the quality factor Q_n = 7. In this experiment, the semiconductor devices were placed at a distance of 5 cm from the ^{241}Am-Be source, and the exposure period was 16.75 hours. Since the total absorbed dose, for that distance, is $\dot{D}_{tot}$ = 13.714 mGyh^{-1} and the total equivalent dose is $\dot{H}_{tot}$ = 24 mSvh^{-1}, the total absorbed dose for material components is $\dot{D}_{tot}$ = 229.71 mGy and the total equivalent dose is H_{tot} = 402 mSv [12].

The dose of ^{60}Co gamma source is 2000 Gy, with an energy of 1.25 MeV and, a half-life time of 5.27 years. The samples were placed in a controlled environment at a distance of 150 mm away from the radioactive source with glass between them. The dose rate was 100 Gyh^{-1} which was measured by an electrometer with ionization chamber TW 30012-0172 produced by PTW, Germany. The measurement uncertainty of the system is less than 1.2 % [12, 13].

Both irradiations, those from the ^{241}Am-Be source and those from the ^{60}Co gamma source were performed in the air at a temperature of 21 °C and relative humidity of 40 % to 70 % [12].

Before and after every step of the irradiation series and parallel resistance, open-circuit voltage, short-circuit current, fill factor and efficiency have been measured. The measurements were performed on the solar panels, in highly controlled conditions at room temperature, which have previously been removed from the irradiation room.

Five measurements of the parameters of the solar cells have been performed:

– first measurement: just before neutron irradiation,
– second measurement: just after neutron irradiation,
– third measurement: 30 days after neutron irradiation (just before gamma irradiation),
– fourth measurement: just after gamma irradiation, and
– fifth measurement: 30 days after gamma irradiation.

In order to perform the long-term isothermal annealing *i. e.* to give panels enough time to recover, the third and fifth measurements have been undertaken 30 days after the irradiation. Because of that, the changes occurring in the samples after the first irradiation (neutron) can be considered permanent. Standard measurement equipment (the professional digital multimeter AMPROBE 33XR) was used for measurement. The combined measurement uncertainty for all measurements was less than 1.2 % [14, 15].

RESULTS AND DISCUSSION

The basic solar cell parameters before and after neutron and gamma irradiation are shown in figs. 1-5. Incident radiation particles interact with the atoms in the crystalline lattice through collisions which causes displacements of atoms from their positions. That leads to the degradation of the transport properties of the material which directly affects the minority carrier's lifetime. The most common defects in silicon are vacancies, self-interstitials, impurities, and dopants which could enter into different interactions and create some point defects which are undesirable, like compensator and recombination centers [16]. Those centers affect solar cells' performance. All of these effects reduce the lifetime of minority carriers in the base layer. The final result is an increasing series resistance, fig. 1 [17].

Neutrons as heavy particles cause radiation damage in silicon crystalline through a displacement of atoms from their positions in the lattice. This distortion and destruction of local lattice structure are called Frenkel defects. If neutron irradiation creates stable defects in the material which already has impurity atoms, donors, or implanted atoms that could form complex defects. Those defects behave as recombination

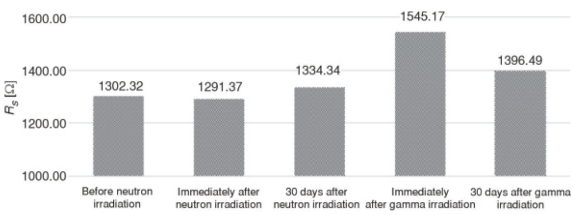

Figure 1. Solar panel series resistance during the successive neutron and gamma irradiation

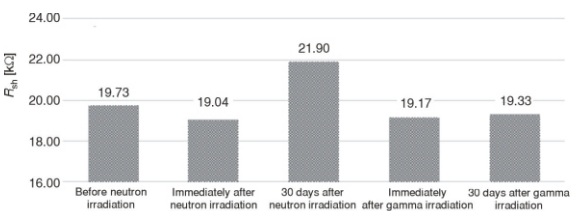

Figure 2. Solar panel parallel resistance during the successive neutron and gamma irradiation

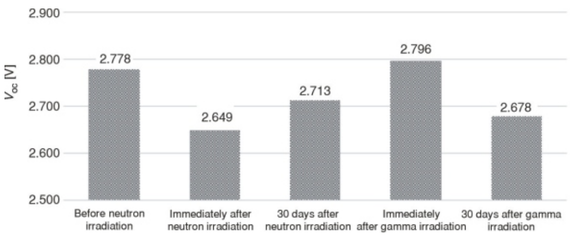

Figure 3. Solar panel open-circuit voltage during the successive neutron and gamma irradiation

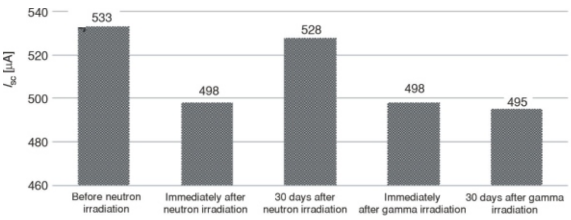

Figure 4. Solar panel short-circuit current during the successive neutron and gamma irradiation

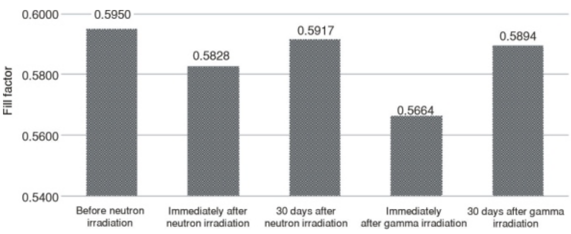

Figure 5. Solar panel fill factor during the successive neutron and gamma irradiation

sites or traps which leads to a significant decrease in minority carrier lifetime. This results in a deterioration of electrical parameters of the solar cells, such as series resistance *Rs*, output current, and finally efficiency [18], as is shown in figs. 1-5.

Gamma rays (high energy photons) interact with material and create two types of effects. The first one is ionization and the second one is atomic displacement. Ionization is caused by a Photoelectric effect, Compton scattering, and pair production (if the energy of incident radiation is above several hundred keV) Interstitial primary knock-on atom (PKA), vacancy, and complex of them form a deep level in bandgap (so-called the generation-recombination center). The recombination centers in the bulk regions cause the reduction of a carrier lifetime [16, 19].

The vacancies and interstitials are unstable defects due to their mobility in silicon at room temperature. Because of that, long-term isothermal annealing at room temperature was used for this experiment. During the long-term annealing process, the vacancies move through the lattice forming more stable defects like divacancies and vacancy-impurity complexes. The annealing process rearranges defects formed by radiation which results in a decreaseinthe effectiveness of the damage over time. Moll [20] describes the enhancement of the effective doping concentration for longer annealing times.

The impact of high-energy radiation (by two different types, neutron, and gamma) on silicon solar cells is much higher and creates more damage compared to only one type of radiation. Ejected atom in a crystalline lattice creates a vacancy. That atom could stay at the interstitial position or it could be recombined with the vacancy. Mobility of vacancies causes their possible combining with impurities or other vacancies. As a result, there has been a significant deterioration of all solar cell parameters, figs. 1-5.

CONCLUSION

A change in the electric properties of solar cells under successive neutron and gamma irradiation was observed. Except for the fill factor, which showed relatively steady values, the combination of those two types of radiation caused deterioration of all solar cell parameters: increasing series resistance and decreasing parallel resistance, open-circuit voltage, short-circuit current, and efficiency. All of these effects are mainly related to the minority carrier's lifetime [21]. The lifetime of minority carriers is sensitive to defects, induced by the radiation, which mostly acts as recombination points, and the decrease in the minority carrier lifetime reduced the parameters of the solar cells.

AUTHORS' CONTRIBUTIONS

Both authors wrote the article together. In addition, all the authors arranged, reviewed, and discussed the results within the article.

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СУКЦЕСИВНО НЕУТРОНСКО И ГАМА ОЗРАЧИВАЊЕ И ЊИХОВ УТИЦАЈ НА КАРАКТЕРИСТИКЕ СОЛАРНИХ ЋЕЛИЈА

Испитани су ефекти сукцесивног неутронског и гама зрачења на параметре комерцијалних соларних ћелија. Соларни панели су били изложени неутронском зрачењу, а након 30 дана опоравка, гама зрачењу. Серија мерења параметара соларних ћелија предузета је у циљу утврђивања поузданости соларних ћелија у условима сукцесивног озрачивања различитих врста зрачења. Параметри соларних ћелија мерени су пре и после сваког корака озрачивања и уочен је процес опоравка. Сврха овог рада је да прикаже ефекте и неутронског и гама зрачења на исти узорак соларне ћелије.

Кључне речи: соларни панел, гама зрачење, неутронско зрачење, I-U карактеристика, редна отпорност, паралелна отпорност, напон празног хода, струја кратког споја