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Effect of gamma radiation on the aged mono-crystalline silicon Solar cells

[1]Davud Mostafa Tobnaghi, [2]Rahim Madatov and [3]Tohid Banki

[1]*Department of Electrical Engineering, Parsabad Moghan Branch, Islamic Azad University, Parsabad Moghan, Iran.*
[2]*Inistitute of Radiation Problems, Azerbaijan National Academy of Science, Baku, Azerbaijan.*
[3]*Department of Electrical Engineering, Bilesavar Moghan Branch, Islamic Azad University, Bilesavar Moghan, Iran.*

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ABSTRACT

The change in output parameters of the aged and old mono-crystalline silicon solar cells was investigated under the irradiation of different doses of gamma ray. Experimental results showed that the main characteristics such as efficiency, open circuit voltage, short circuit current etc. changed to different extent with increasing the gamma radiation doses from 50 to 2000 krad. At low dose, 50krad, electric properties of the aged silicon solar cells were improved. From 1000 to 2000 krad I_{sc} and η parameters decrease proportionally to the increase of the gamma radiation doses whereas V_{oc} is only slightly decreased. Large amount of radiation induced defects in the high dose have been formed. Obtained results could lead to new designs of silicon solar to increasing their applications in radiation environments.

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INTRODUCTION

Using the clean and free energy from the sun mono-crystalline silicon solar cells are still the key options in various commercially available for photovoltaic solar energy conversion. However proved under usual working conditions, solar cells are prone to the effects of aging, which could deteriorate their output parameters. The effects of solar cells aging on their electrical characteristics will be further when the solar cells work in adverse environmental conditions such as high temperature and radiation exposure. During their operating lifetime, solar cells are exposed to radiation environments in which they are used, such as military and civil nuclear environments, etc. Studying radiation resistance of solar cells is interesting not only for the purpose of predicting lifespan of solar cells, but also to improve design of solar cells used in high radiation environments. This is especially important for solar cells used in PV systems located near nuclear power plants (Razykov, T.M., *et al*., 2011; Diab, H.M., *et al*., 2013; VASIĆ, A., *et al*., 2007).

The irradiation of solar cells by high-energy levels of radiation in the form of gamma rays, neutrons, charged particles, etc. leads to radiation defects and electrical damage in the solar cells bulk and results a significant degradation of the electrical parameters of silicon solar cells. However, over time the lifetime and performance of the solar cells is reduced (Vasic, A., *et al*., 2010; Dejan Nikolic, *et al*., 2013; Jayashree, B., *et al*., 2006).

When silicon solar cells irradiated with gamma rays, two types of radiation damage occur within it: displacement damage and ionization effects. Displacement damage is the movement of atoms from their initial location in the crystal lattice to another placement that results a defect in the crystal lattice of solar cells. Ionization effect is the generation of electron-hole pairs in the bulk of solar cell that results radiation effects. These defects mostly act as recombination points that decreased the diffusion length and life time of minority carrier as well as increased internal parameters of cells. output parameters of solar cell such as maximum output power, fill factor, efficiency, short circuit current, and open circuit voltage-P_m, ff, η, I_{sc}, V_{oc} respectively strongly depend on internal parameters of solar cells such as series resistance, R_S, saturation current, I_0 and ideal factor, n. it has been proved that increasing each of above internal parameters of solar cell causes that the output characteristics of solar cells decreased (Ali, A., *et al*., Saad, A.M., 2002; Ashry, M., S. Fares, 2012; Sze, S.M., 1981).

Hence the changes in the electrical parameters of the aged mono-crystalline silicon solar cells samples under various doses of gamma radiation are presented in this paper.

Corresponding Authors: Davud Mostafa Tobnaghi, Department of Electrical Engineering, Parsabad Moghan Branch, Islamic Azad University, Parsabad Moghan, Iran.
E-mail: d.mostafa.t@gmail.com

Experimental method:

In this paper, the five batches samples each batch contain three commercially available the aged silicon solar cells are used for experimental measurements. The solar cells were fabricated mono-crystalline structure with using phosphorus diffusion into a p-type silicon wafer. All 15 samples were irradiated with ^{60}Co gamma source with energy of 1.23MeV. The batches samples 1, 2…, 5 were irradiated with dose 50, 100, 500, 1000, 2000 krad respectively. Table 1 shows the basic specifications of samples that were examined in the present study.

Irradiation of cells was carried out in professional laboratory at the institute of Radiation Problems of Azerbaijan National Academy of science.

Voltage-current (I-V) characteristics and output parameters of all samples before and after irradiation were measured. To obtain of solar cells I-V characteristics samples were illuminated by reflective lamp with Light intensity equal to100 $\frac{mw}{cm^2}$. The measurements were performed at room temperature with highly accurate measuring equipment.

Table 1: Properties of five samples of the experimental solar cells

Cells type	V_{OC} [mv]	I_{SC} [mA/cm^2]	P_{mmp} [mw/ cm^2]	FF	η [%]
Si-monocrystalline	435-570	20-34	4-8.5	0.33-0.61	4.4-9.4

RESULTS AND DISCUSSION

Voltage-current characteristics of five batches the aged mono-crystalline silicon solar cells samples before and after gamma radiation have been showed in figure 1 (The results of each batch are averaged). As can be seen, electrical Characteristics of solar cells at low doses of gamma irradiation (50 krad) improved. This means that by low doses of gamma ray aging and declined solar cells can be recovered. At higher doses (100-2000 krad) high energy of gamma radiation produces defects in solar cells that causes to deterioration in solar cell's characteristics. From figure 1, output and fundamental parameters of solar cells like maximum output power (P_m), fill facture (ff), efficiency (η), short circuit current (I_{sc}), and open circuit voltage (V_{oc}), can be extracted (Khuram Ali, *et al*., 2013; Tuzun, O., *et al*., 2011; Elani, U.A.I., 2010; Alurralde, M., *et al*., 2004). The measurements are normalized to the values obtained before samples irradiated.

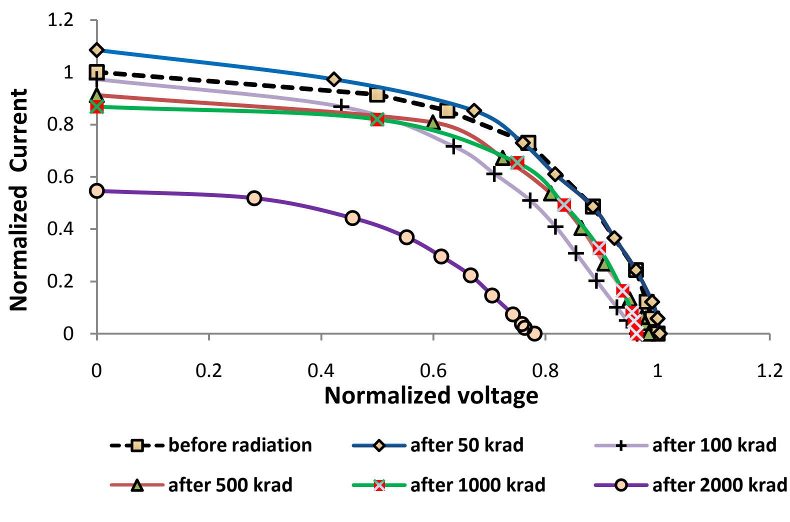

Fig. 1: V-I characteristics of mc- silicon solar cells before and after irradiation

The fill factor (FF) parameter for solar cells can be expressed as

$$FF = \frac{V_{\mathrm{mp}} \cdot I_{\mathrm{mp}}}{V_{\mathrm{oc}} \cdot I_{\mathrm{sc}}} \tag{1}$$

Where V_{oc} and I_{sc} are the open circuit voltage and short circuit current, V_{mp} and I_{mp} are the voltage and the current at a maximum power point respectively.

The efficiency (η) for a solar cell is given by

$$\eta = \frac{V_{\mathrm{oc}} I_{\mathrm{sc}} FF}{P_{\mathrm{in}}} \tag{2}$$

Where, P_{in} is the incident light power (Sathyanarayana Bhat, P., *et al*., 2014).

Figure 2, shows the influence of gamma radiation on output parameters of solar cells samples. As can be seen, except at low doses, gamma radiation causes a significant Reduction in the I_{sc} , P_m and η while the V_{oc} slightly reduced. Gamma Radiation also causes changes in the fundamental and inner parameters of solar cells so that diffusion length and lifetime of minority carriers decreased and reverse saturation current (I_0) and ideal factor increased (n) (Imaizumi, M., *et al*., 1997).

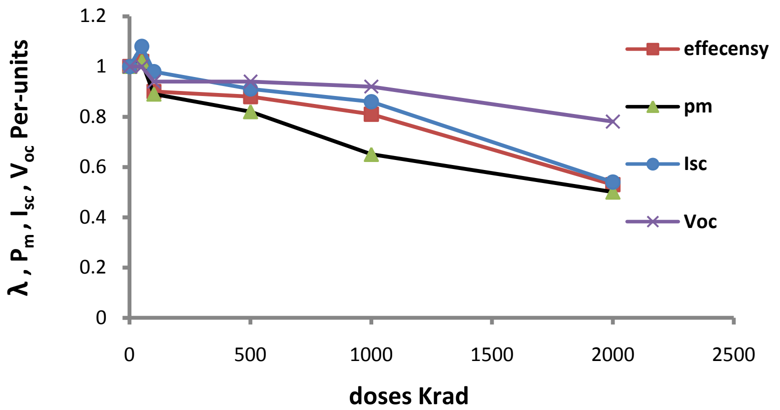

Fig. 2: Output parameters of solar cells affected by gamma irradiation

The short circuit current is because of the generation and collection of light-generated carriers. It was determined as:

$$I_{sc} = q.G.P \tag{3}$$

Where q is electron charge, G is number of carriers generated in the solar cell, and P is the collection probability of carriers. Since the amount of G remains approximately constant, decrease in the I_{sc} essentially relevant to the collection probability. The collection probability of carriers depends on the surface passivation and the minority carrier diffusion length in the base. Gamma radiation causes the activation of solar cell surface and also increases defects near the upper surface. Ultimately recombination is increased in the solar cell so P is decreased. In the base layer, irradiation of γ ray reduces the lifetime of minority carrier and the diffusion length of minority carriers much smaller than the base thickness, $L_n \ll d_p$, the P value can be determined as:

$$P = \frac{\alpha L_n}{\alpha L_n + 1} \tag{4}$$

Where α is light absorption coefficient, $L_n = \sqrt{D_n \tau_n}$, and D_n is the electron diffusion coefficient and τ_n is the minority carrier lifetime.

The open circuit voltage can be obtained using the following equation:

$$V_{oc} = \frac{nkT}{q} ln \frac{I_{sc}}{I_0} \tag{5}$$

According to Eq. (5), V_{oc} does not change significantly with increasing n and I_0 and decreasing I_{sc}. (Guseynov, N.A., *et al*., 2007).

According to Figures 1 and 2, the output parameters and V-I characteristics of samples at a dose of 50 krad has been increased. To further investigation, Table 2 shows the output parameters of three samples, A, B and C (from batch 1) before and after 50 krad gamma irradiation. As can be seen, all parameters of three samples after irradiation was increased, except for fill factor values, which in B and C samples cases showed decreased and in A sample showed increased. It seems the crystalline atoms of the aged mono-crystalline silicon solar cells that have displaced from their initial place with time, by low dose gamma irradiation partially returned to their original state where the aged cells have showed a recovery in the their characteristics (Horiuchi, N., *et al*., 2000; Kuendig, J., *et al*., 2003).

Table 2: Output parameters of three samples of the aged solar cells before and after exposed whit 50 krad gamma radiation

Samples	Dose [krad]	V_{OC} [mv]	I_{SC} [mA/cm^2]	V_{mmp} [mv]	I_{mmp} [mA/cm^2]	P_{mmp} [mw]	FF	η [%]
A	0 50	505 500	25.8 30.5	300 320	17.8 20.1	5.3 6.4	0.4 0.42	6.2 7.5
B	0 50	510 505	29.2 32.5	300 320	23.5 23.5	7 7.5	0.47 0.46	8.3 8.8
C	0 50	520 522	27.5 29.5	400 350	20.1 23.5	8 8.2	0.56 0.52	9.4 9.6

Conclusion:

Changes in output parameters of 15 samples the aged mono-crystalline silicon solar cells under gamma irradiation were investigated. Experimental results showed at low dose (50 krad) the I-V characteristics of samples were improved. This means that using low doses of gamma ray the aging and declined mono-crystalline silicon solar cell can be recovered. A deterioration of the electric properties of solar cells was observed when the gamma dose was increased (100-2000 krad). Except the fill factor, which in some cases showed increased or relatively steady values, gamma radiation causes a significant Reduction in the I_{sc} and η while the V_{oc} is slightly reduced.

The decrease in short circuit current and other fundamental parameters is mainly related to the minority carrier life time. The life time of minority carriers is sensitive to the radiation induced defects that mostly act as recombination points, and the decrease in the minority carrier life time reduced the solar cells parameters.

Large amount of radiation induced defects in the high dose have been formed. Obtained results could lead to new designs of mono-crystalline silicon solar cells for development of their application in different conditions.

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