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Variations in the Electrical Parameters of Degraded Silicon Solar Cells

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ABSTRACT: In this experimental work, the change in output parameters of the mono-crystalline silicon solar cells was investigated under gamma irradiation. Experimental results showed that the main parameters of solar cells such as efficiency, open circuit voltage, short circuit current etc. changed to different extent with increasing the gamma radiation doses from 100 to 2000 krad. The parameters of I_{sc} and η 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.

***Keywords*:** silicon solar cell, gamma radiation, current–voltage characteristics, short circuit current, open circuit voltage

INTRODUCTION

Mono-crystalline silicon solar cells are still the basic elements for photovoltaic conversion of solar energy. Regardless of the very high standards in the production of mono- crystalline silicon solar cells, it has been proved that silicon solar cells are extremely sensitive to electromagnetic radiation with substantially short wavelengths, such as x-rays and gamma-rays. 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 [1-4].

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 [5-8].

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

MATERIAL AND METHODS

In this paper, the four samples of the commercially silicon solar cells having same characteristics are used for experimental measurements. The specifications of samples are shown in Table1. The solar cells were fabricated mono-crystalline structure using phosphorus diffusion into a p-type silicon wafer. All four samples were irradiated with ^{60}Co gamma source with the energy of 1.23 MeV. The samples 1, 2…, 4 were irradiated with dose 100, 500, 1000, 2000 Krad respectively. Irradiation of cells was

carried out in laboratory at the institute of Radiation Problems of Azerbaijan National Academy of science.

Voltage-current (I-V) characteristics 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 to 1000 W/m^2 (corresponding to AM1.5).

The measurements were performed at room temperature with highly accurate measuring equipment.

Table 1.Properties of four samples of the experimental solar cells (before irradiation)

Cells type	VOC $[mV]$	ISC $\frac{mA}{cm^2}$	Pmmp $\frac{mW}{cm^2}$	FF	η [%]
Si-monocrystalline	570	34	14	0.72	13.9

Notes: Condition for measurement: 1000 W/m^2, AM 1.5, 25^{0}C.

RESULTS AND DISCUSSION

Voltage-current characteristics of four solar cell samples before and after various doses of gamma radiation at under AM 1.5 illumination condition have been showed in figure 1. As can be seen, I-V characteristics of cells deteriorated with increasing gamma irradiation. From figure 1, fundamental parameters of solar cells like open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (ff) and efficiency (η) could be extracted.

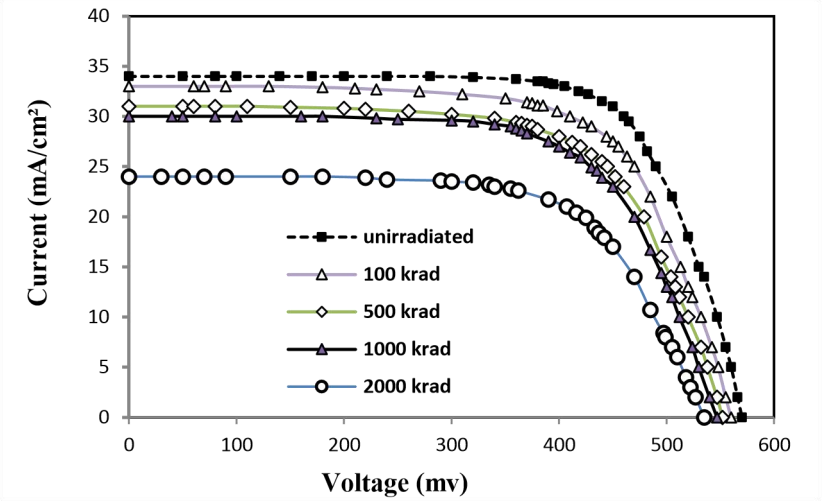


Fig 1. The *I–V* characteristics of silicon solar cell irradiated with various doses of gamma radiation

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

$$FF = \frac{V_{mp} \cdot I_{mp}}{V_{oc} \cdot I_{sc}} \quad (1)$$

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

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (2)$$

Where, P_{in} is the incident light power [14].

Figure 2 shows the changes in solar cells parameters as a function of gamma dose. The parameters are normalized to the values obtained before samples irradiated. It was found that the degradation of the solar cell parameters is dependent on the gamma radiation dose and the irradiation has affected the solar cell parameters to a certain extent. There is no substantial variation in the fill factor, which in

some cases showed increased or relatively steady values. According to the results, the gamma radiation causes a significant Reduction in the short circuit current and efficiency while the open circuit voltage is slightly reduced. The decrease in the efficiency and short circuit current of solar cells under gamma radiation could be related to the minority carrier life time. The minority carrier life time is sensitive to the radiation induced defects and the decrease in the minority carrier life time reduced the electric properties of solar cells. According to results a large amount of radiation induced defects in the high dose have been formed [9-12]. The detail of solar cells parameters degraded under gamma radiation doses are shown in table 2.

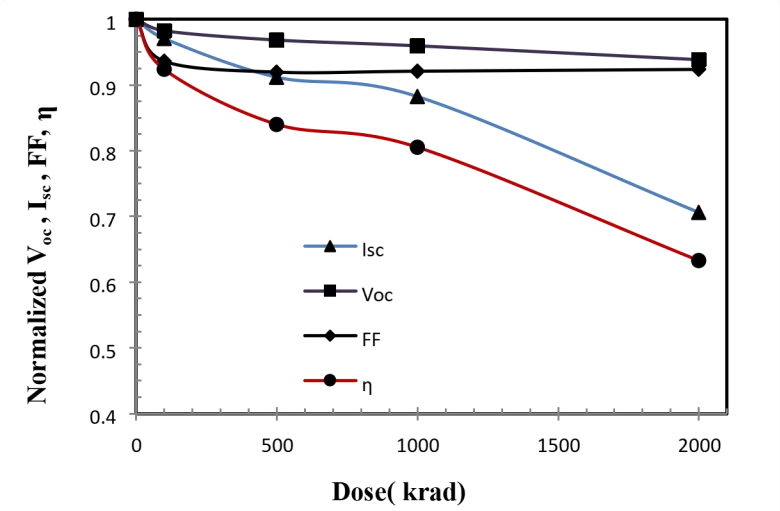


Fig 2. Normalized solar cell parameters as a function of gamma radiation dose

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

$$I_{sc} = q.\,G.\,P \qquad (3)$$

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 [13], 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 ɣ 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:

$$P = \frac{\alpha L_n}{\alpha L_n + 1} \qquad (4)$$

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:

$$V_{oc} = \frac{nkT}{q} ln \frac{I_{sc}}{I_0} \qquad (5)$$

According to Eq. (5) V_{oc} does not change significantly with increasing n and I_0 and decreasing I_{sc}. [13].

Table 2. Degradation of solar cell parameters under gamma radiation doses

solar cell Sample	ɣ doses [*Krad*]	VOC [*mV*]	ISC *mA* [— / cm^2]	Vmp [*mV*]	Imp *mA* [— / cm^2]	FF	η [%]

Mono-crystalline silicon	0	570	34	450	31	0.72	13.95
	100	560	33	440	29	0.674	12.47
	500	552	31	420	27	0.662	11.34
	1000	547	30	420	25.9	0.663	10.87
	2000	535	24	407	21	0.665	8.54

CONCLUSIONS

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.

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