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EXPERIMENTAL STUDY ON THE VARIATION OF DEGRADED SILICON SOLAR CELLS PARAMETERS

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Abstract

In the lifetime and under ordinary working conditions, solar cells prone to the effects of aging and their electrical parameters are degrading continually. In this paper, to simulate and accelerate the effects of aging, solar cells were exposed to the different doses of gamma radiation, since gamma radiation and aging produces similar effects in semiconducting devices. The current-voltage characteristics and spectral photo current of mono-crystalline solar cells were studied before and after the gamma irradiation. Experimental results showed that the gamma radiation causes a significant Reduction in the short circuit current (I_{sc}) and efficiency (η) while the open circuit voltage (V_{oc}) is slightly reduced. The spectral photo current shows that, by increasing irradiation dose, reducing the current occurred at lower wavelengths and defects is mainly inflicted to region close to the surface of solar cells. Obtained results could lead to novel designs of silicon solar cells with purpose of increasing their possible applications.

Keywords: Silicon solar cell, Gamma radiation, Spectral photo current, Current-voltage characteristics, Short circuit current, Open circuit voltage

1. Introduction

The Using the clean and free energy from the sun, crystalline silicon solar cells are still the mostly used element for solar cell production [1]. Regardless of the very high standards in the production of solar cells, proved that under ordinary working conditions, solar cells are prone to the effects of aging. This process of aging is more pronounced when the cells are in some kind of radiation fields (natural space and atmospheric, as well as military and civil nuclear environments, etc.) or exposed to the large variations of temperature. Since operating conditions often prevent regular maintenance, stability of output electrical characteristics and lifetime of solar cells are of great significance [2-4].

Because of radiation and aging produces similar effects in solar cells [5], studying radiation resistance of solar cells is interesting not only for the purpose of predicting lifespan and end-of-life output characteristics of solar cells, but also to improve design of solar cells used in high radiation environments. In this paper, to simulate and accelerate of the effects of degradation on solar cells parameters, solar cells were exposed to the different doses of gamma radiation [6].

Crystalline silicon solar cells, however, exhibit a response to electromagnetic radiation having substantially shorter wavelengths such as gamma ray. 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 silicon solar cells parameters. The lifetime of the semiconductor device is restricted by the degree of radiation damage that the solar cell receives [7].

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 [8]. 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 [9]. output parameters of solar cell such as maximum output power, fill factor, efficiency, short circuit current, and open circuit voltage - *Pmax*, *FF*, η, *Isc*, *Voc* respectively strongly depend on internal parameters of solar cells such as series resistance, RS, saturation current, I0 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 [10].

The solar cells generally exhibit good spectral response to visible radiation, which occupies the 400-800 nm wavelength region of the electromagnetic spectrum. In this paper, spectral characteristic determines how a solar cell responds to select of narrow bands of irradiance. The main reason to measure the spectral photo current is to use it as a tool to understand the performance of the solar cell. In fact, that blue light produces electron-hole pairs near the cell surface and red light absorbed in the bulk of cell [11].

Also, this paper investigated output characteristics of silicon solar cells in working mode, which corresponds to increased average cloud cover during the year, after being exposed to different doses of gamma radiation. Experimental results show that lower illumination lead to reversible changes in measured characteristics of solar cells, while higher illumination result irreversible degradations.

2. Experimental 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 Table 1. The solar cells were fabricated using phosphorus diffusion into a p-type mono-crystalline silicon wafer. The subsurface diffusiondoped *n*-type layer thickness was d_n = 2-3-μm, and the *p*-type base thickness was d_p = 300-μm .

All four samples were irradiated with Co60 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 professional laboratory at the institute of Radiation Problems of Azerbaijan National Academy of science.

Current-Voltage (I-V) and spectral characteristics of all samples before and after irradiation were measured. To obtain the I-V characteristics in forth quadrant, the samples were illuminated by reflective lamp with Light intensity equal to 1000 W/m^2 (corresponding to AM1.5). The spectral characteristic of the solar cells was measured at wavelength ranging from 400 nm to 1200 nm using spectral response measurement system.

The I-V characteristics of all solar cell samples under different illumination levels (between 50 and 700 W/m2) was measured before and after radiation. Light intensity was varied by changing the distance of samples from the light source, and was controlled using a calibrated lux-meter.

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	V_{OC} [mv]	I_{SC} [mA/cm^2]	P_{max} [mw/ cm^2]	*FF*	η [%]
Si-monocrystalline	570	34	14	0.72	13.95

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

3. Results and Discussion

3.1. I-V characteristics under illumination

Current-Voltage characteristics of four solar cell samples before and after various doses of gamma radiation at under AM1.5 illumination condition have been showed in Fig. 1. As can be seen, I-V characteristics of cells deteriorated with increasing gamma irradiation. From Fig. 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 [12].

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

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

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

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

where, P_{in} is the incident light power [13, 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.

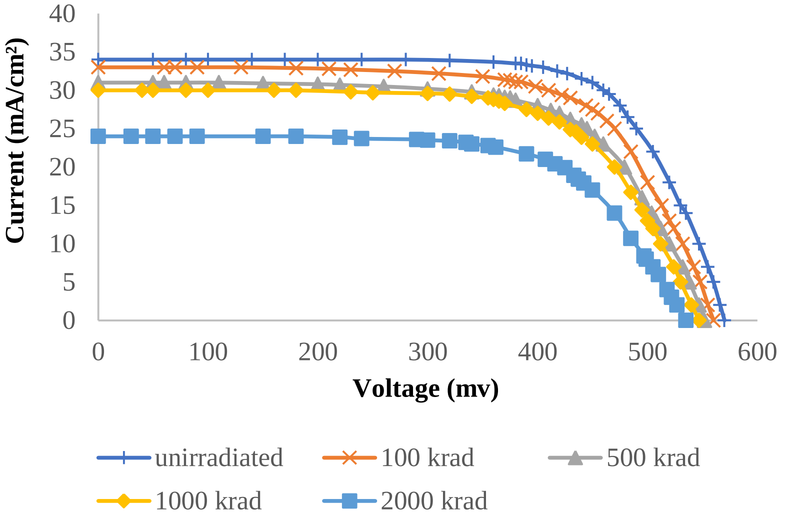

Fig. 1. The I-V characteristics of silicon solar cell irradiated with various doses of gamma radiation.

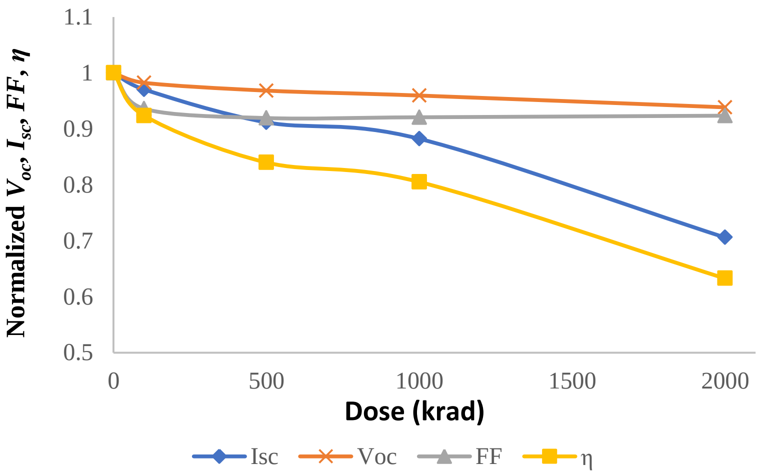

Fig. 2. Normalized solar cell parameters in terms of gamma radiation dose.

The gamma radiation defects produced in solar cells interact with the existing defects. This interaction can lead to the formation of additional electrically and optically active centres in the p-n junction and base regions, which play the role of new generation-recombination centres and lead to a decrease in minority carrier life time (τn). Decrease in the minority carrier life time lead to reduce the electric properties of solar cells. According to results a large amount of radiation induced defects in the high dose have been formed [15].

3.2. Spectral response measurement

Figure 3 shows the change in spectral photo current, I (λ), of silicon solar cell samples under gamma irradiation. It can be seen that in the whole wavelength range the highest photo current values belong to the un-irradiated solar cell and the photo current values decreased with increasing gamma radiation dose [16].

According to the results, a significant degradation in photo current output of samples has been found for lower wavelengths region and there is no considerable degradation for higher wavelength range. This means that the effect of gamma radiation on silicon solar cells and production defects is greater in region close to the surface cells [17]. The light photons near the lower wavelengths of the spectrum are absorbed and produce electron-hole pairs near the solar cell surface. The solar cells derive a smaller fraction of their power from higher wavelength of the solar spectrum and are less sensitive to degradation of diffusion length in base. It is observed that after irradiation there is variation mainly in the lower wavelength side of the spectrum indicating that the degradation is mainly due to defect creation in the near surface of crystalline silicon solar cells. As well as, a solar cell that exposed to high dose of gamma radiation (2000 Krad), radiation damage and degradation of photo current occurred in the whole wavelength range [18,19].

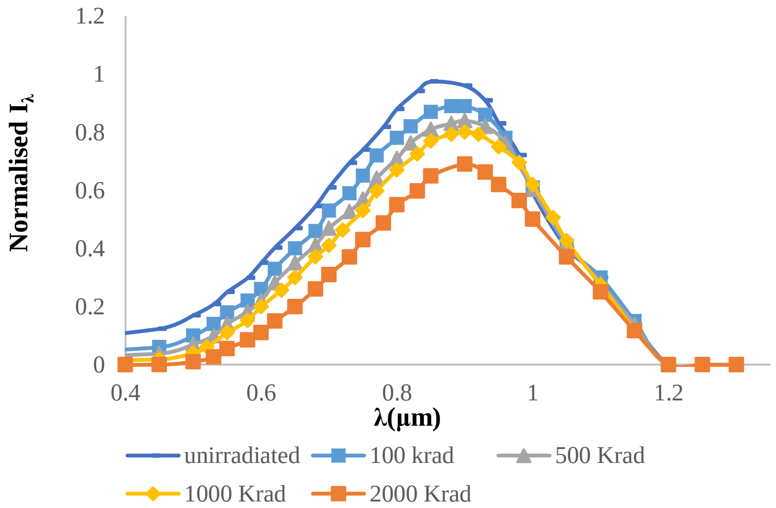

Fig. 3. Photo current of silicon solar cells in terms of light wavelength under various doses of gamma irradiation.

3.3. Electrical parameters under low light conditions

Although effects of gamma irradiation on measured solar cell samples was degradation of fundamental parameters but mostly these effect is on the short-circuit current, since radiation induced defects mainly affects the transport mechanisms in the solar cells. Presence of the recombination centres, small minority carrier lifetime and diffusion length, as a result of either gamma irradiation or aging, finally leads to the decrease of the output power of solar cells [20]. Dependence of the *Isc* on the absorbed dose for different illumination level (85-640 w/m2) was shown in Fig. 4. Steeper decrease of the short circuit current for higher illumination levels demonstrate that recombination centres could be both optically activated and activated by irradiation. So, solar cells exposed to the higher values of solar irradiation during their performance could exhibit greater decrease in the initial short circuit current value. Similar action was observed for the *Voc*, Fig. 5.

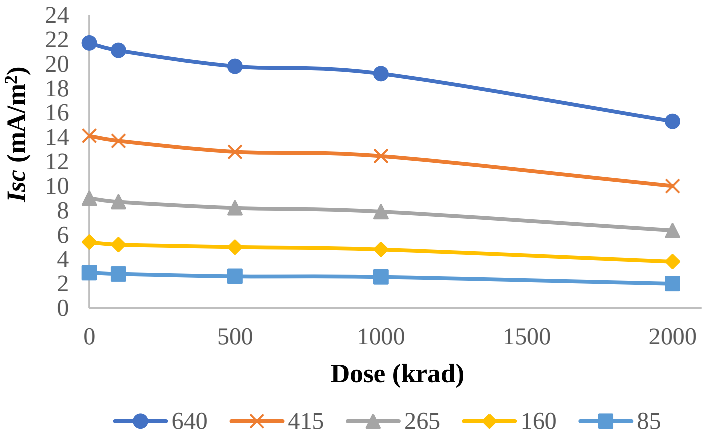

Fig. 4. Dependence of the *Isc* on gamma dose for different illumination.

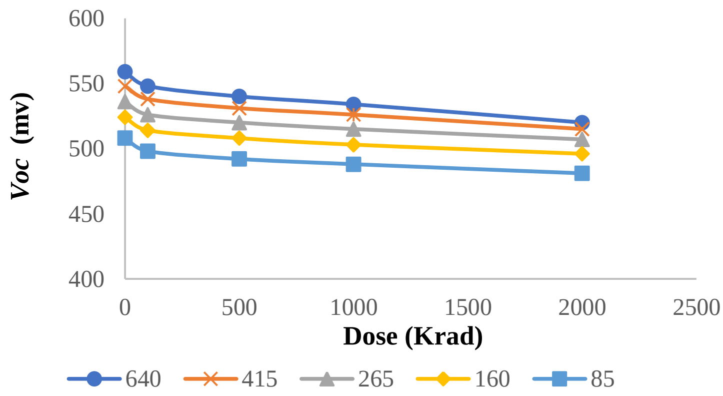

Fig. 5. Dependence of the *Voc* on gamma doses for different illumination.

4. Conclusions

Taking into account that irradiation and aging produces similar effects in the solar cell, to simulate and accelerate the effects of aging on solar cells parameters, four solar cell samples were exposed to the different doses of gamma radiation. The effects of different doses of gamma radiation on the properties of silicon solar cells and also output characteristics of cells in working mode after being exposed to different doses of gamma ray have been studied and the following conclusions were drawn:

- 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's life time. The life time of minority carriers is sensitive to the radiation induced defects that mostly act as recombination centers, and the decrease in the minority carrier life time reduced the mobility of the charge carriers, and then the solar cells transport parameters.
- According to the spectral photo current, after gamma irradiation, the most of the cells performance is lost in the low wavelength of the spectrum. This means that production defects due to gamma radiation occurred near the cell surface.
- Examination of silicon solar cells performance in working mode showed that the aged solar cells exposed to the higher values of solar irradiation during their performance could exhibit greater decrease in the initial their parameters.

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