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Recovery of the Electrical Parameters of Degraded Solar Cells by Ultrasonic Treatment

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Abstract – In the lifetime of solar cells and under normal operating conditions, electrical parameters of solar cells are degrading continuously because solar cells are ageing during outdoor exposure, which could deteriorate their electrical characteristics. In this paper, to simulate and accelerate the effects of aging, solar cells are exposed to the different doses of gamma radiation, since gamma radiation and aging produces similar effects in semiconducting devices. The electrical parameters of degraded silicon solar cells can be significantly recovered by ultrasonic treatment (UST). The restores of the silicon solar cells parameters such as efficiency (η), open circuit voltage (V_{oc}), short circuit current (I_{sc}), among other, after ultrasonic treatment is related to a redistribution of the radiation defects and an increase in the homogeneity of a solar cells crystal structure.

Keywords: Silicon solar cells, Voltage-current characteristics, Efficiency, Gamma radiation, Ultrasonic treatment

1. Introduction

The mono-crystalline silicon is still the mostly used element for photovoltaic solar energy conversion. Regardless of the very high standards in the production of mc- silicon solar cells, it is proved that during their operating lifetime, silicon solar cells prone to the effects of aging and their parameters are degraded. This degradation is mainly due to temperature, humidity, system bias effects and solar irradiation. This process of degradation is more pronounced when the solar cells are in some kind of radiation fields or exposed to the large variations of temperature. Since the gamma radiation and aging produces similar effects on solar cells, 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 the aging effects on solar cells parameters, solar cells are exposed to the different doses of gamma radiation [1-5].

As is known, the irradiation of semiconductor devices by gamma radiation leads to the accumulation of radiation defects in the semiconductor bulk. These defects mostly act as recombination points that decrease the diffusion length and minority carrier life-time and frequently result in a significant deterioration of the electrical characteristics of devices, in particular, silicon solar cells. Photoelectric parameters of silicon solar cells such as maximum output power (P_m), open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (FF) and efficiency (η) strongly depend on minority carrier life time (τ) [6-9].

Using the subsequent controlled action upon the defect structure in the base region and p–n junction of silicon solar cells, it is possible to produce the necessary correction of the cell characteristics. One traditional method of solar cells improvement is thermal annealing, however thermal annealing have received much attention in recent years. According to the results of numerous investigations dedicated to the use of acoustic methods for the recovery of characteristics of semiconductor materials, it is reasonable to expect that ultrasound treatments (UST) can greatly restore the properties of degraded silicon solar cells [10-13].

The ultrasonic wave energy is absorbed predominantly by the solar cells defects and favors their redistribution toward the equilibrium state. Since the gamma irradiation mostly creates mobile radiation defects in solar cells, the ultrasonic wave acts predominantly upon these defects and favors their redistribution [14].

Hence the use of ultrasonic treatment for recovery of electrical parameters of deteriorated mono crystalline silicon solar cells is presented in this paper.

2. Experimental Methods

In this paper, the two samples of the commercially mono-crystalline silicon solar cells having the same characteristics are used for experimental measurements. The solar cells were fabricated mono-crystalline structure using phosphorus diffusion into a p-type silicon wafer.

The samples were p-n junction very close to the front surface by diffusing 3μm-thickness n-type layer doped into

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an approximately 300-µm -thickness p-type layer. The two samples were irradiated with ^{60}Co gamma-ray with the energy of 1.23 MeV. The samples *A* and *B* were irradiated with doses 500 and 1000 krad, respectively. Irradiation of solar cells samples were carried out in professional laboratory at the institute of Radiation Problems of Azerbaijan National Academy of science, Baku, Azerbaijan.

Each of the samples were consecutively subjected to a two-stage UST using longitudinal acoustic waves, which were propagated perpendicular to the samples through piezo disk. In the first stage (UST_1), the ultrasonic treatment was performed in the following condition: frequency, f_{UST1}=50 MHZ, time duration, t=90 m. The second stage (UST_2) was performed in f_{UST2}=50 MHZ, time duration, t=240 m.

Current -Voltage ($I-V$) characteristics of samples were measured before and after irradiation as well as after ultrasonic treatment. 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.

3. Results and Discussion

3.1. $I-V$ Characteristics under gamma radiation

$I-V$ characteristics of two solar cell samples before and after 500 and 1000 krad doses of gamma radiation under AM 1.5 illumination conditions have been showed in Fig. 1. As can be seen, $I-V$ characteristics of cells were 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.

The fill factor (FF) parameter for solar cells can be expressed as [16]:

$$FF = \frac{V_{mp}.V_{mp}}{V_{oc}.I_{sc}} \qquad (1)$$

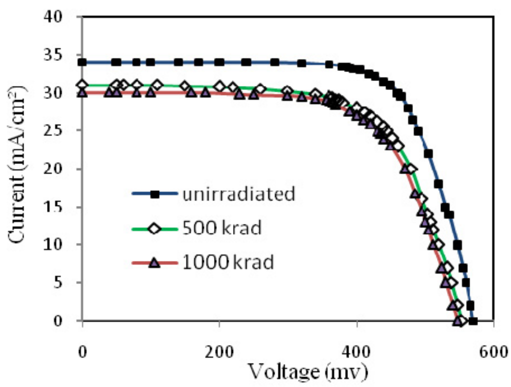

Fig. 1. The $I-V$ characteristics of silicon solar cell irradiated with various doses of gamma radiation

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 for a solar cell is given by [16]:

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

where P_{in} is the incident light power.

Fig. 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. According to results, a large amount of radiation induced defects in the high dose have been formed [15, 17]. The detail of solar cells parameters were degraded under gamma radiation doses are shown in Table 1.

The short circuit current was determined as [10]:

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

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, a drop in the I_{sc} essentially related

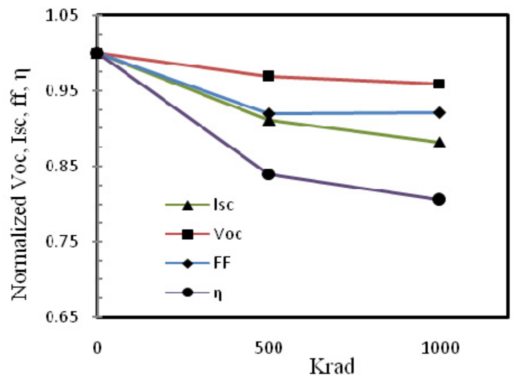

Fig. 2. Normalized solar cell parameters dependences of gamma radiation dose

Table 1. Degradation of solar cell parameters under gamma radiation doses

Solar cell sample	Gamma doses [$Krad$]	V_{oc} [mV]	I_{sc} [$\frac{mA}{cm^2}$]	V_{mp} [mV]	I_{mp} [$\frac{mA}{cm^2}$]	FF	η [%]
Mono-crystalline silicon	0	570	34	450	31	0.72	13.95
	500	552	31	420	27	0.662	11.34
	1000	547	30	420	25.9	0.663	10.87

to a decrease in the collection probability value. The diffusion length of minority carriers in the base is much smaller than the base thickness, $L_n << d_p$, the P value can be determined as [10]:

$$p = \frac{\alpha L_n}{\alpha L_n + 1} \quad (4)$$

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

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 centers in the $p-n$ junction and base regions, which play the role of new generation-recombination centers and lead to a decrease in τ_n and, hence, in the P and I_{sc} values [14, 18].

3.2. Ultrasonic treatment

Fig. 3 shows the $I-V$ characteristics of solar cells samples. As can be seen, the gamma-irradiation leads to deterioration of the initial characteristic, which is manifested by a decrease in the V_{oc} and I_{sc}. The subsequent ultrasonic treatments (UST_1, and especially, UST_2) improved the characteristics and shifted them toward the initial curves.

Obviously, the solar cell current due to thermogenerated carriers is directly proportional to the concentration of generation-recombination centers. Then, an increase or decrease in the I_{rev} value at a virtually constant slope of the temperature dependence of I_{rev} curve after various treatments is the evidence of the proportional increase or decrease in the concentration of solar cell defects, whereas a change in this slope with the I_{rev} value after various treatment is indicative of changes both in the concentration of defects and in the mechanism of current transfer. This conclusion is verified by the temperature dependences of I_{rev} measured at U_{rev}=0.4 V in the Fig. 4.

The activation energy of current transfer, which is evidence for both diffusion and generation mechanisms of current transfer, determined from the slope of the temperature dependence of reverse current. As shown in Fig. 4, the slope of temperature dependence of I_{rev} upon gamma irradiation decreases and the activation energy drops. After the UST_1 and especially UST_2, the activation energy increases. This is indicative of the appearance of a diffusion component in the current transfer and a decrease in the concentration of generation–recombination centers in the solar cells.

Fig. 5 shows the effect 500 krad of gamma-irradiation and each UST stage on the electrical parameters of silicon solar cells. As can be seen, After the UST_1 and especially UST_2 all electrical parameters of solar cell increases, which become substantially closer to the initial values.

Additionally, Fig. 6 shows the effect of 1000 krad gamma-irradiation and each UST stage on the electrical

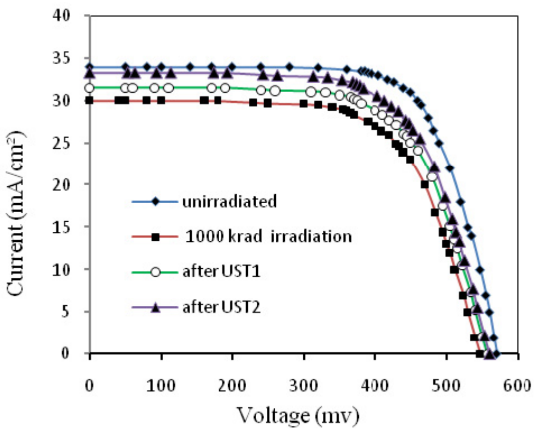

Fig. 3. The $I-V$ characteristics of silicon solar cell before and after gamma irradiation to a dose of 1000 krad, and after each stage of ultrasonic treatment.

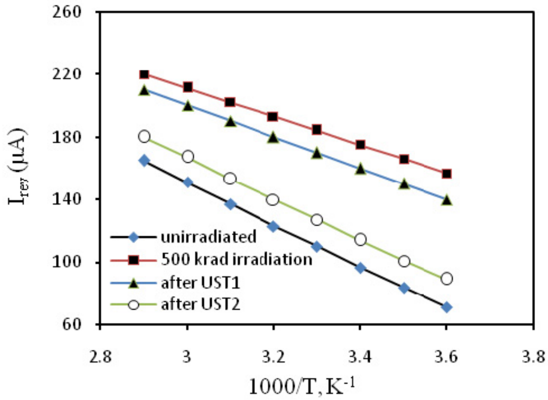

Fig. 4. Temperature dependences of the reverse current measured at U_{rev}= 0.4 V in the silicon solar cell in various states

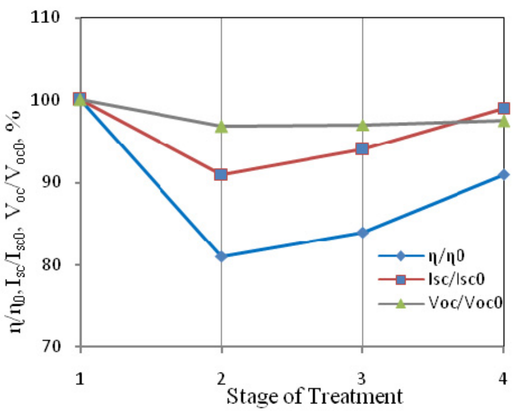

Fig. 5. Variation of the relative values of short -circuit current (I_{sc}/I_{sc0}), open-circuit voltage (V_{oc}/V_{oc0}), and efficiency (η / η_0) for a silicon solar cell in various states: (1) unirradiated state; (2) under 500 krad gamma-irradiation; (3, 4) after UST_1 and UST_2.

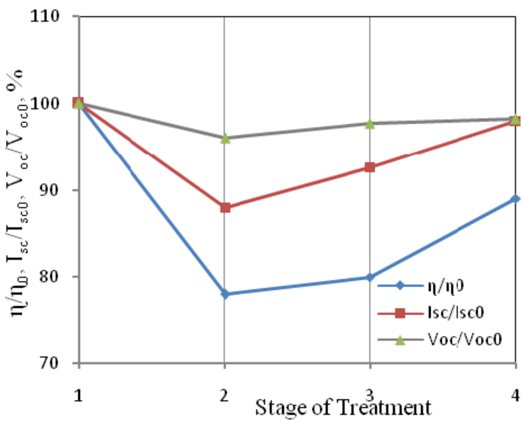

Fig. 6. Variation of the relative values of short-circuit current (I_{sc}/I_{sc0}), open-circuit voltage (V_{oc}/V_{oc0}), and efficiency (η/η_0) for a silicon solar cell in various states: (1) unirradiated state; (2) under 1000 krad gamma-irradiation; (3, 4) after UST_1 and UST_2.

parameters of silicon solar cell. According to the results, the restoration in the electrical parameters of solar cells degraded under gamma radiation by ultrasonic treatment has been obtained. As can be seen, 10-15% improvement in efficiency was observed after $UST_{1,2}$.

Therefore, the ultrasonic wave energy is absorbed predominantly by the solar cells defects and favors their redistribution toward the equilibrium state. Since the irradiation with gamma radiation mostly creates mobile radiation defects in solar cells, the ultrasonic treatment acts predominantly upon these defects and tends their redistribution [19]. Thus, the results of this study demonstrate that the ultrasonic treatment partly restores the electrical parameters of degraded silicon solar cells [20].

4. Conclusions

In this paper, to simulate and accelerate the effects of aging, solar cells were exposed to the different doses of gamma radiation. Two mono-crystalline silicon solar cell samples were exposed to the different doses of gamma radiation. The effects of gamma radiation on the electrical parameters of silicon solar cells and subsequent ultrasonic treatment of degraded solar cells have been studied and the following conclusions were drawn:

- A deterioration of the electric properties of solar cells was observed when the solar cells were irradiated by gamma ray (500 and 1000 krad). The gamma radiation causes a significant reduction in the Isc 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 carriers life time. The life time of minority carriers is sensitive to the radiation induced defects that mostly act as recombination points, by decreasing in the minority carrier life time, the photoelectric parameters of solar cells are reduced.
- The ultrasonic wave energy is absorbed predominantly by the solar cells crystal lattice defects and tends their redistribution that partly restores the solar cells crystal structure.
- The ultrasonic treatment results show the silicon solar cells that their efficiency is dropped by 20% compared to the initial value can be greatly recovery by UST.

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