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Studying photoelectric parameters of the aging silicon solar cells by thermal annealing

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ABSTRACT

To simulate and accelerate of the aging effects, silicon solar cells were exposed to the different doses of co^{60} gamma radiation. The current–voltage (I–V) characteristics of mono-crystalline solar cells under AM1.5 illumination condition were studied before and after the gamma irradiation. Experimental results showed that the solar cell parameters such as open circuit voltage (V_{oc}), short circuit current (I_{sc}) and efficiency (η) decrease with the increase of the gamma radiation doses. The photoelectric parameters of mono crystalline silicon solar cells degraded under gamma radiation can be significant recovered by MHz-frequency ultrasonic treatment (UST). The performance of UST to restores of the aged silicon solar cells parameters compared to thermal annealing method has been shown in this paper.

1. Introduction

The mono-crystalline silicon solar cells are still the mostly used element for photovoltaic solar energy conversion. 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 (Razykov et al., 2011; Diab et al., 2013; Alurraldea et al., 2004). Since the gamma radiation and aging produces similar effects in 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 of the aging effects on solar cells parameters, solar cells were exposed to the different doses of gamma radiation (Vasic et al., 2007).

When silicon solar cells irradiated with gamma rays, the radiation damage occur within it. These defects mostly act as recombination points that decreased the diffusion length and life time of minority carrier. Photoelectric parameters of silicon solar cell such as maximum output power, open circuit voltage, short circuit current, fill factor and efficiency -P_m, V_{oc}, I_{sc}, ff, η respectively strongly depend on minority carrier life time (τ). Decrease in the life time of minority carrier causes decrease the output characteristics of solar cells (Vasic et al., 2010; Nikolic et al., 2013; Jayashree et al., 2006; Saad, 2002; Sze, 1981).

One traditional method for solar cells improvement is thermal annealing, but thermal annealing have received much research 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 can be restoration in the properties of degraded silicon solar cells (Khuram et al., 2013). Using the subsequent ultrasonic treatment on the degraded silicon solar cells, it is possible atoms of crystalline silicon that have been displaced from their initial place by gamma irradiation, can be removed from their place using UST and return to the previous location to produce the necessary correction of the cells characteristics (Sathyanarayana et al., 2014).

Hence the use of ultrasonic treatment for recovery of photoelectric properties of mono crystalline silicon solar cells deteriorated under gamma radiation is presented in this paper.

2. Experimental methods

In this paper, the four samples of the mono crystalline silicon solar cells having same characteristics are used for experimental

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measurements. The specifications of samples are shown in Table 1. The solar cells were fabricated mono-crystalline structure using phosphorus diffusion into a p-type silicon wafer. The solar cell forms an n-p junction very close to the front surface by diffusing 2-3-μm-thick n-type doping into an approximately 300-μm -thick p-type silicon.

All four samples were irradiated with ^{60}Co gamma source. The samples 1 and 2 were irradiated with 5 kGy and other samples, 3 and 4 with 10 kGy. Irradiation of cells was carried out in professional laboratory at the institute of Radiation Problems of Azerbaijan National Academy of science.

Thermal annealing steps (at 150 ^{0}C, 200 ^{0}C and 250 ^{0}C: each step during 30 minutes) for two samples, 1and 3, was performed so that after each step the all electrical parameters of cells have been measured.

The samples of 2 and 4 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 (UST1), the ultrasonic treatment was performed in the following condition: frequency, f_{UST1}=50 MHZ, duration, t=90 m. The second stage (UST2) was performed in f_{UST2}=50 MHZ, duration, t=240 m.

Voltage-current (I-V) characteristics of all samples before and after irradiation as well as after thermal annealing and ultrasonic treatment were measured. To obtain of solar cells I-V characteristics samples were illuminated by reflective lamp with Light intensity equal to 1000 $\frac{w}{m^2}$ (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	V_{OC} [mv]	I_{SC} [mA/cm²]	P_{mmp} [mw/ cm²]	FF	η [%]
Si-monocrystalline	570	34	14	0.72	13.95

Note: Condition for measurement: 1000 W/m², AM 1.5, 25^{0}C.

3. Results and discussion

3-1. *I-V* characteristics under gamma radiation

Voltage-current characteristics of four solar cell samples before and after 5 and 10 kGy doses of gamma radiation under AM1.5 illumination conditions have been showed in figure 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 from (Xiaohan and Ashraf, 2014).

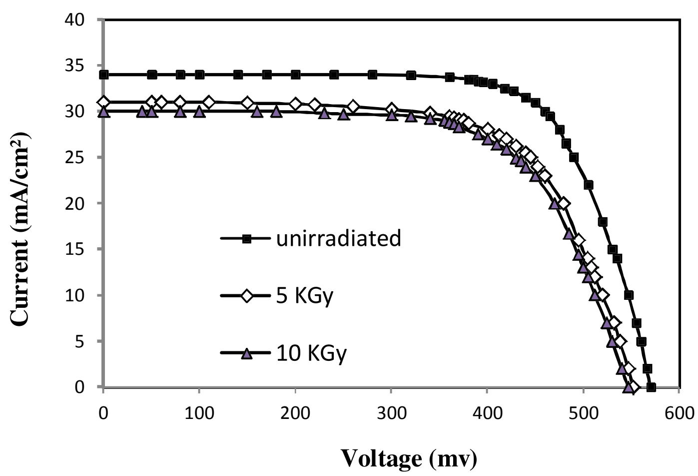

Fig. 1. The *I*–*V* characteristics of silicon solar cell before and after gamma irradiation

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 (Horiuchi, et al., 2000).

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. 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. There is no substantial variation in the fill factor, which in some cases showed increased or relatively steady values. 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 (Wu et al., 2011).

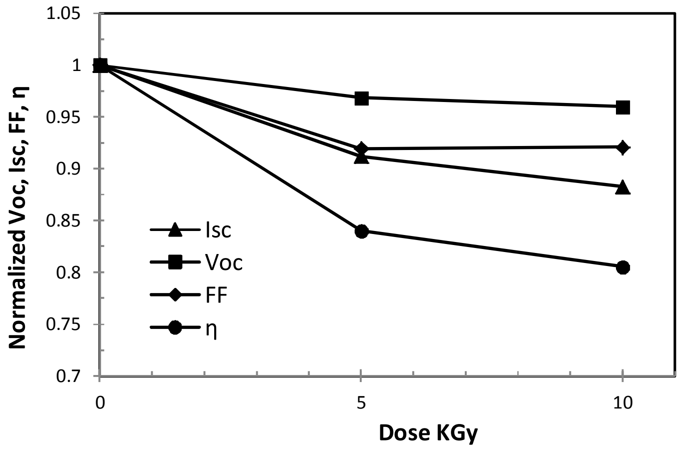

Fig. 2. Normalized solar cell parameters in terms of gamma radiation dose

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

$I_{sc} = q \times G \times P$ (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 minority carrier diffusion length in the base. Gamma radiation induced defects in solar cells mostly act as recombination points (Zhiqiang et al., 2013). Ultimately recombination is increased in the solar cell so P is decreased. In the base layer, the diffusion length of minority carriers much smaller than the base thickness, $L_n \ll d_p$, the P value can be determined as:

$P = \frac{\alpha L_n}{\alpha L_n + 1}$ (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:

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

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

3.2. Annealing improvement

Fig. 3 and Fig. 4 show change in the short circuit current and efficiency of the samples 1 and 3 after 30 minutes thermal annealing steps: 150 ^{0}C, 200 ^{0}C and 250 ^{0}C under AM1.5 illumination condition. At low dose, 5 KGy, A significant improvement in electric parameters of solar cells was observed after the thermal annealing while there is no recovery has occurred in sample parameters degraded with 10 KGy dose of gamma irradiation.

At 5 KGy dose, the percentage of gain in short circuit is 5%. Similarly 17% of improvement in efficiency was observed after thermal annealing. The thermal annealing causes the crystalline atoms of the aged solar cells (or exposed to gamma rays) that have been displaced from their initial place, can be removed from their place and return to the previous location where the cells showed a recovery from radiation damage. At 10 KGy dose the defects are stable and don't recovery by thermal annealing (Kuendig et al., 2003). The experimentally measured values are listed in Table 2.

3.3. Ultrasonic Treatment

Fig. 5 shows the effect of each UST stage on the parameters of sample 2 irradiated with 5 kGy dose of gamma radiation. As can be seen from these data, the subsequent USTs restore the parameters of solar cells, which become substantially closer to the initial values.

As well as, Fig. 6 shows the effect of each UST stage on the parameters of sample 4 irradiated with dose of 10 kGy gamma radiation.

According to results, the restore 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 UST1, 2.

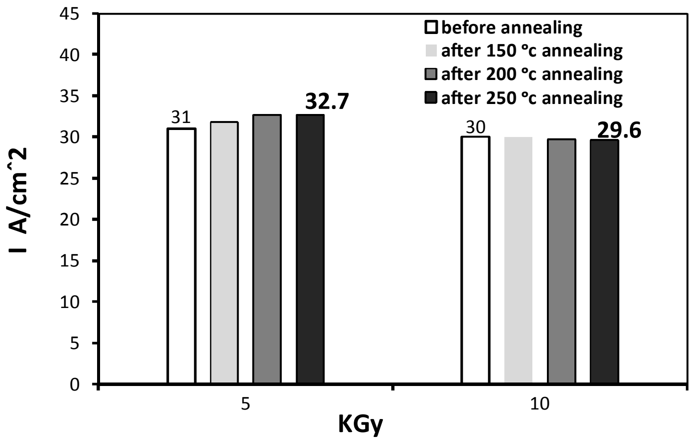

Fig. 3. The recovery in solar cells short circuit current by thermal annealing

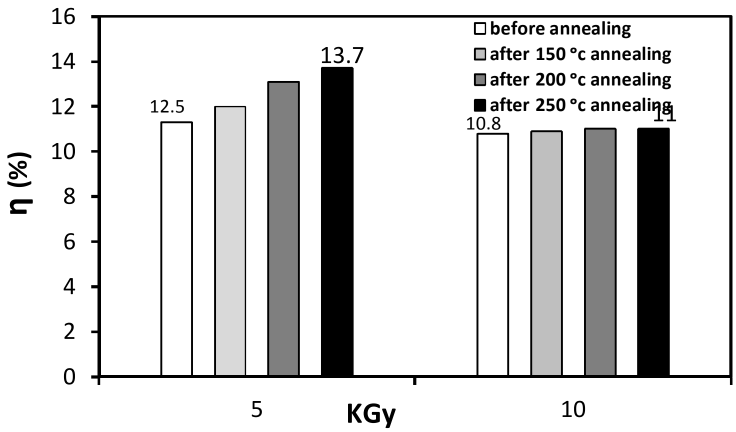

Fig. 4. The recovery in solar cells efficiency by thermal annealing

Table 2: Recovery of solar cells by thermal annealing

Cell samples	Gamma irradiation (kGy)	Degradation ratio (%)		Recovery ratio of I_{sc} (%)			Recovery ratio of η (%)		
		I_{sc}	η	150 °c	200 °c	250 °c	150 °c	200 °c	250 °c
1	5	8.8	19	93.5	96	96	86	94	98.2
3	10	11.7	22.5	88.2	87.3	87	78	78.8	78.8

Notes: Degradation ratio = $\frac{a-b}{a} \times 100\%$

Recovery ratio = $\frac{c}{a} \times 100\%$

a: Short Circuit Current or Efficiency before gamma irradiation.
b: Short Circuit Current or Efficiency after gamma irradiation.
c: Short Circuit Current or Efficiency after thermal annealing

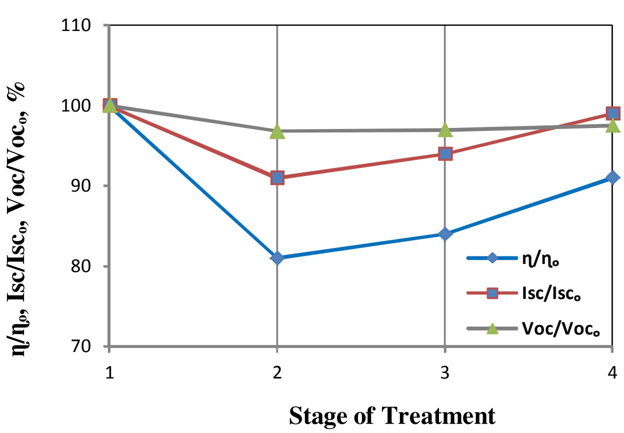

Fig. 5. Variation of the relative values of short -circuit current (Isc/Isc_o), open-circuit voltage (Voc/Voc_o), and efficiency (η/η_o) for a silicon solar cell in various states: (1) unirradiated state; (2) under gamma-irradiation to a dose of 5 kGy; (3, 4) after UST_1 and UST_2 respectively

The ultrasonic treatment causes the crystalline atoms of the solar cells with time operation (10-20 year) that have been displaced from their initial place, can be removed from their place and return to the previous location where the solar cells showed a restores in their parameters (Guseynov et al 2007; Tobnaghi and Madatov, 2014).

Abstained results from thermal annealing and ultrasonic treatment shows that the solar cell its efficiency with time operation drop more than 20% can be restores to near initial value by UST while the recovery is not possible by using thermal annealing.

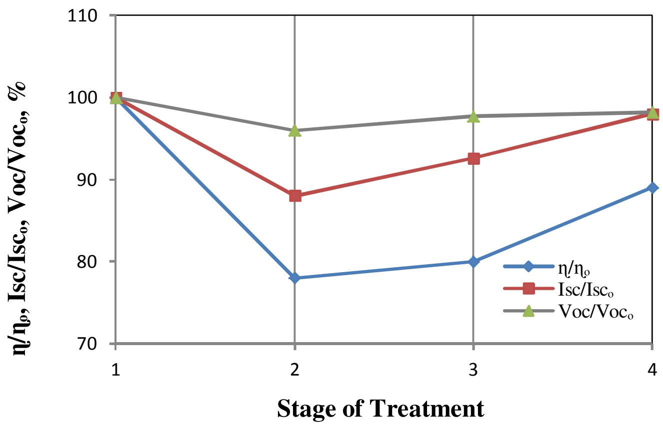

Fig. 6. Variation of the relative values of short -circuit current (Isc/Isc_o), open-circuit voltage (Voc/Voc_o), and efficiency (η/η_o) for a silicon solar cell in various states: (1) unirradiated state; (2) under gamma-irradiation to a dose of 10 kGy; (3, 4) after UST1 and UST2 respectively

4. Conclusion

To simulate and accelerate of 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 subsequent thermal annealing and ultrasonic treatment on solar cells degraded by gamma irradiation have been studied and the following conclusions were drawn:

- A deterioration of the electrical parameters of solar cells was observed when the gamma dose was increased (5 to 10 kGy). 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. Decrease in the minority carrier life time reduced the solar cells parameters.
- Thermal annealing results show the aging solar cells that their efficiency is missed 19% compared to the initial value, can be recovery by thermal annealing.
- The solar cells that with time operation, their efficiency drop greater than 20%, can't recovered by thermal annealing.
- The performance of ultrasonic treatment to restores of the aged silicon solar cells parameters compared to thermal annealing method has been shown, the UST can do recover the silicon solar cells parameters that its efficiency drop greater than 20%.

References

Alurraldea M, Tamasib MJL, Brunob CJ (2004). Experimental and theoretical radiation damage studies on crystalline silicon solar cells. Solar Energy Materials & Solar Cells, 82(4): 531-542.

Diab HM, Ibrahim A, ElMallawany R (2013). Silicon Solar Cells as a Gamma Ray Dosimeter. Measurement, 46(9): 3635–3639.

Guseynov NA, Olikh YM, Askerov SG (2007). Ultrasonic treatment restores the photoelectric parameters of silicon solar cells degraded under the action of ^{60}Co gamma radiation. Technical Physics Letters, 33(1):18–21.

Horiuchi N, Nozaki T, Chiba A (2000). Improvement in electrical performance of radiation-damaged silicon solar cells by annealing. Nuclear Instruments and Methods in Physics Research, 443(1): 186–193.

Jayashree B, Radhakrishna MC, Anil A, Saif AK, Meulenberg A (2006) The Influence of High-Energy Lithium Ion Irradiation on Electrical Characteristics of Silicon and GaAs Solar Cells.

IEEE transactions on nuclear science, 53(6): 3779-3785.

Kuendig J, Goetz M, Shah A, Fernandez E (2003). Thin film silicon solar cells for space applications: Study of proton irradiation and thermal annealing effects on the characteristics of solar cells and individual layers. Solar Energy Materials and Solar Cells, 79: 425–438.

Khuram A, Sohail AK, MatJafri MZ (2013). 60Co γ-irradiation Effects on Electrical Characteristics of Monocrystalline Silicon Solar Cell. international journal of electrochemical science, 8: 7831 – 7841.

Nikolic D, Stankovic K, Timotijevic L (2013). Comparative Study of Gamma Radiation Effects on Solar Cells and Phototransistors. International Journal of Photoenergy, Article ID 843174.

Razykov TM, Ferekides CS, Morel D, Stefanakos E, Ullal HS (2011). Solar photovoltaic electricity: Current status and future prospects. Solar Energy, 85(8): 1580–1608.

Saad A M (2002). Effect of cobalt 60 and 1 MeV electron irradiation on silicon photodiodes solar cells. Canadian Journal of Physics, 80(12): 1591-1599.

Vasic A, Vujisic M, Loncar b, Osmokrovic p (2007). Aging of solar cells under working conditions. journal of optoelectronics and advanced materials, 9(6):1843 – 1846.

Vasic A, Vujisic M, Stankovic K, Jovanovic B (2010). Ambiguous Influence of Radiation Effects in Solar Cells. Proceedings of Progressin Electromagnetics Research Symposium Proceedings: 1199–1203.

Sathyanarayana P B, Rao A, Krishnan H, Sanjeev G (2014). A study on the variation of c-Si solar cell parameters under 8Me electron irradiation. Solar EnergyMaterials&SolarCells, 120A: 191-196.

Sze S M (1981). Physics of Semiconductor Devices. 2nd ed NewYork USA Wiley Interscience

Tobnaghi D M, Madatov R 2014 Recovery in the electrical parameters of the aging silicon solar cells by annealing. journal of optoelectronics and advanced materials 16(6): 764 - 768.

Wu H J, Ma W H, Chen X H, Jiang Y, Mei X, Zhang C, Wu X (2011). Effect of thermal annealing on defects of upgraded metallurgical grade silicon. transaction of nonferrous metals society of china, 21: 1340–1347.

Xiaohan Y, Ashraf U (2014). Effect of thermal annealing on P3HT:PCBM bulk-heterojunction organic solar cells: A critical review. Renewable and Sustainable Energy Reviews, 30: 324–336.

Zhiqiang G, JunshengY, Jiang H, Lei Z (2013). Power efficiency enhancement of solution-processed small-molecule solar cells based on squaraine via thermal annealing and solvent additive methods. Solar Energy Materials and Solar Cells, 109: 262–269.