Int. J. Electrochem. Sci., 9 **(2014)** 2824 - 2831

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Experimental Study of Gamma Radiation Effects on the Electrical Characteristics of Silicon Solar Cells

Davud Mostafa Tobnaghi[*], *Ali Rahnamaei, Mina Vajdi*
Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Ardabil, Iran
[*]E-mail: d.mostafa.t@gmail.com

Received: 16 January 2014 / *Accepted:* 4 March 2014 / *Published:* 23 March 2014

For this experimental study, solar cells samples were exposed to the different doses of ^{60}co gamma radiation source. The current–voltage characteristics of mono-crystalline silicon solar cells under AM1.5 illumination condition and their spectral photo current were studied before and after gamma irradiation. Experimental results show 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 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. Deterioration of silicon solar cells parameters by gamma irradiation; this is strongly supported by results of minority carrier lifetime, which show a clearly decreasing minority carrier lifetime as radiation dose increases.

Keywords: solar cell, gamma radiation, spectral photo current, current–voltage characteristics, short circuit current, open circuit voltage

1. INTRODUCTION

Using the clean and free energy from the sun, mono-crystalline silicon solar cells are still the best options for photovoltaic solar energy systems. The electrical characteristics of silicon solar cells are affected by environment condition. During operation of photovoltaic solar cells, they are exposed to radiation such as used in space systems and satellites. 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 [1, 2]. The lifetime and performance of the solar cells is limited by the amount of radiation damage.

Crystalline silicon solar cells, however, exhibit a response to electromagnetic radiation having substantially shorter wavelengths such as gamma ray. 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. The eject electrons from the atoms of the crystal results a track of ionized atoms in the solar cells crystal. 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 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 [3-5].

To investigate the radiation defect for various doses of gamma radiation, it is essential to study the degradation of the minority carrier lifetime. The degradation of minority carrier lifetime results in change in the device properties. The importance of effective minority carrier lifetime to a silicon solar cell's efficiency is reflected in its crucial impact on both short circuit current and open circuit voltage. [6-8].

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 determine 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 produce electron-hole pairs near the cell surface and red light absorbed in the bulk of cell [8].

Hence the changes in the electrical parameters of silicon solar cells samples under various doses of gamma radiation as well as spectral photo current are presented in this paper.

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 Table1. The solar cells were fabricated mono-crystalline structure using phosphorus diffusion into a p-type silicon wafer. All four samples were irradiated with Co^{60} gamma source with the energy of 1.23 MeV. The samples 1, 2…, 4 were irradiated with dose 1, 5, 10, 20 KGy respectively. Irradiation of cells was carried out in professional laboratory at the institute of Radiation Problems of Azerbaijan National Academy of science.

The measurements of the minority carrier lifetime of the solar cells samples were carried out before and after gamma irradiation by using frequency generator, light diode and Tektronix TDS2012B digital storage oscilloscope; so that the light diode is connected to the generator and the solar cell sample is uniformly illuminated by the light diode pulses. When an instant generator voltage is zero the stored minority carriers cannot abruptly fall to zero. The decay of a photocurrent can be observed on oscilloscope and is a lifetime measure [9]. The minority carrier lifetime measuring equipment shows in figure 1.

In this method the solar cell output in an instant is zero but the stored minority carriers cannot abruptly fall to zero.

Voltage-current (I-V) and spectral 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 $1000\ \frac{w}{m^2}$ (corresponding to AM1.5). The spectral characteristic of the solar cells was measured at wavelength ranging from400 nm to 1200 nm using spectral response measurement system.

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_{mmp} [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^{0}C.

Figure 1. minority carrier lifetime measuring equipment

3. RESULTS AND DISCUSSION

3.1. I-V characteristics under gamma radiation

Voltage-current characteristics of four solar cell samples before and after various doses of gamma radiation at under AM1.5 illumination condition have been showed in figure 2. As can be seen, I-V characteristics of cells deteriorated with increasing gamma irradiation. From figure 1, fundamental parameters of solar cells such as open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (ff) and efficiency (η) could be extracted [10-13].

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 [20].

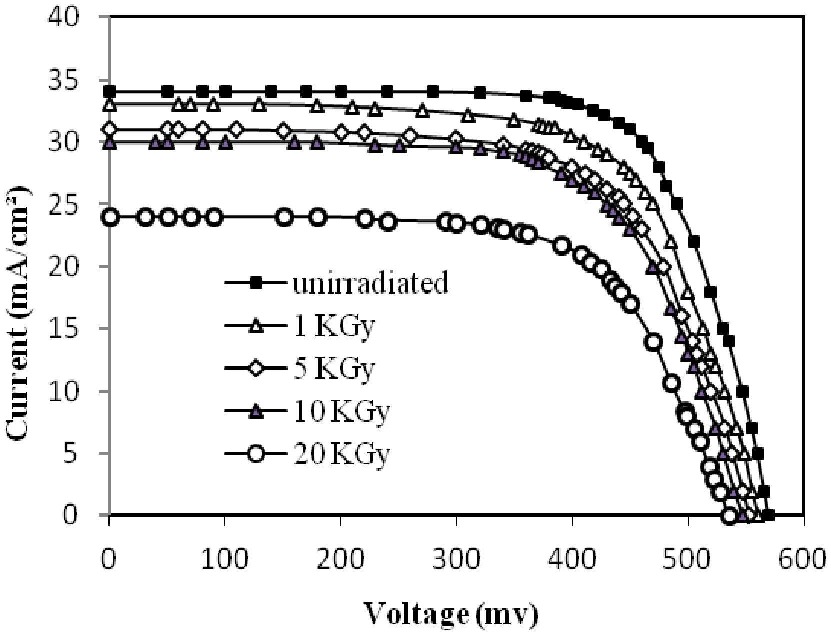

Figure 2. The *I–V* characteristics of silicon solar cell irradiated with various doses of gamma radiation

Figure 3 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 [14-16]. The detail of solar cells parameters degraded under gamma doses of is shown in table 2.

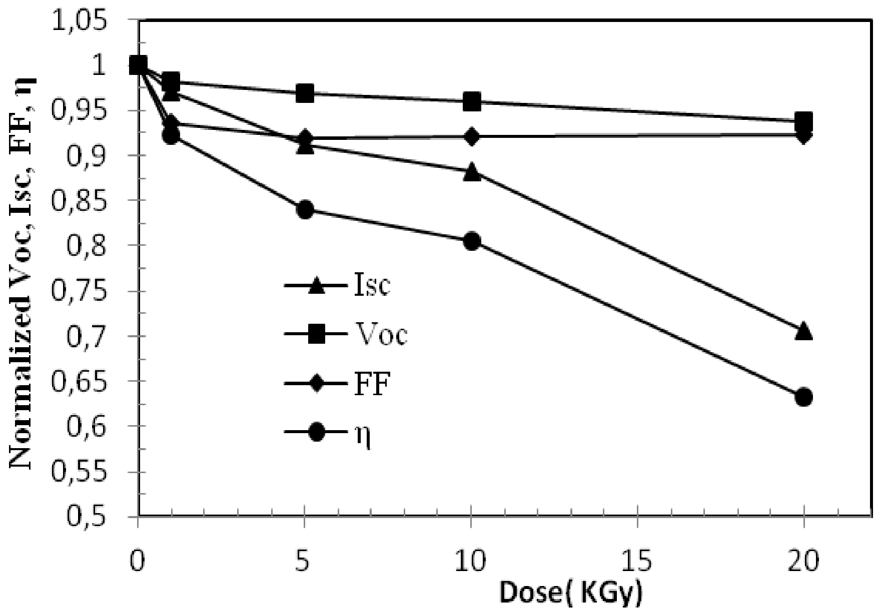

Figure 3. Normalized solar cell parameters as a function of gamma radiation dose

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

solar cell Sample	Gamma doses [KGy]	V_{OC} [mv]	I_{SC} [mA/cm^2]	V_{mp} [mv]	I_{mp} [mA/cm^2]	FF	η [%]
Mono-crystalline silicon	0	570	34	450	31	0.72	13.95
	1	560	33	440	29	0.674	12.47
	5	552	31	420	27	0.662	11.34
	10	547	30	420	25.9	0.663	10.87
	20	535	24	407	21	0.665	8.54

The decrease in short circuit current and other fundamental parameters of solar cells under gamma radiation is mainly related to the minority carrier life time. The minority carrier lifetime of a solar cells, is the average time which a minority carrier can spend in an excited state after electron-hole generation before it recombines. The lifetime of minority carriers is sensitive to the radiation induced defects that mostly act as recombination points [17, 18]. The lifetime is related to the recombination rate by:

$$\tau = \frac{\Delta n}{R} \qquad (3)$$

Where τ is the minority carrier lifetime, Δn is the excess minority carriers concentration and R is the recombination rate.

The variation of minority carrier lifetime of silicon solar cell samples before and after gamma irradiation as a function of dose is shown in Fig. 4.

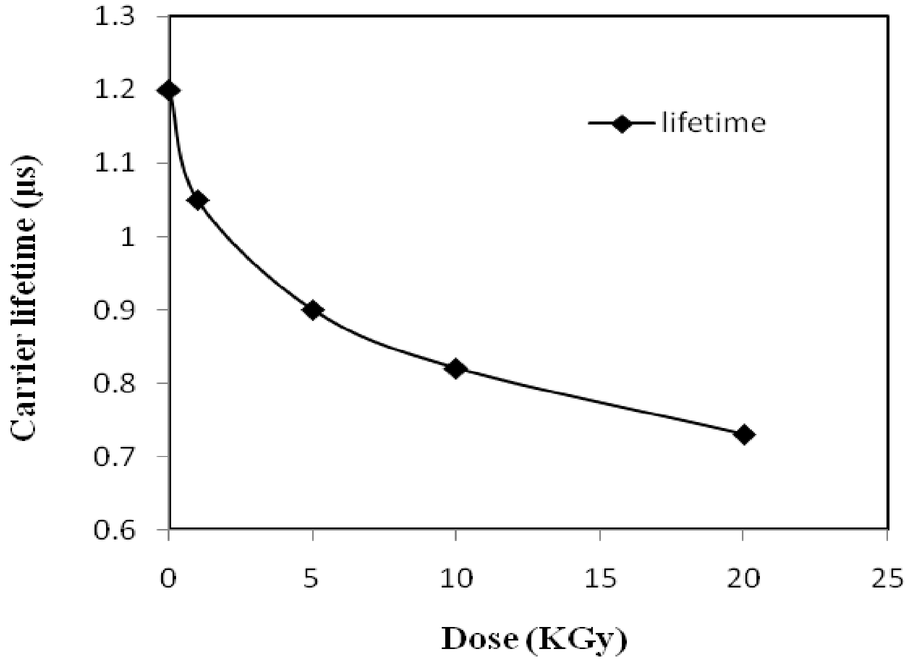

Figure 4. The variation of minority carrier lifetime with various doses of gamma irradiation

Minority carrier diffusion length is a more applicable parameter for solar cell analysis. With increasing the gamma radiation dose, the electron-hole recombination points increases Therefore the concentration of minority carrier traps will increase. Decrease in the minority carrier lifetime reduced the solar cells electrical properties [19].

3.2. Spectral photo current

Figure 5 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.

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. As well as, a solar cell that exposed to high dose of gamma radiation (20 KGy), radiation damage and degradation of photo current occurred in the whole wavelength range [21].

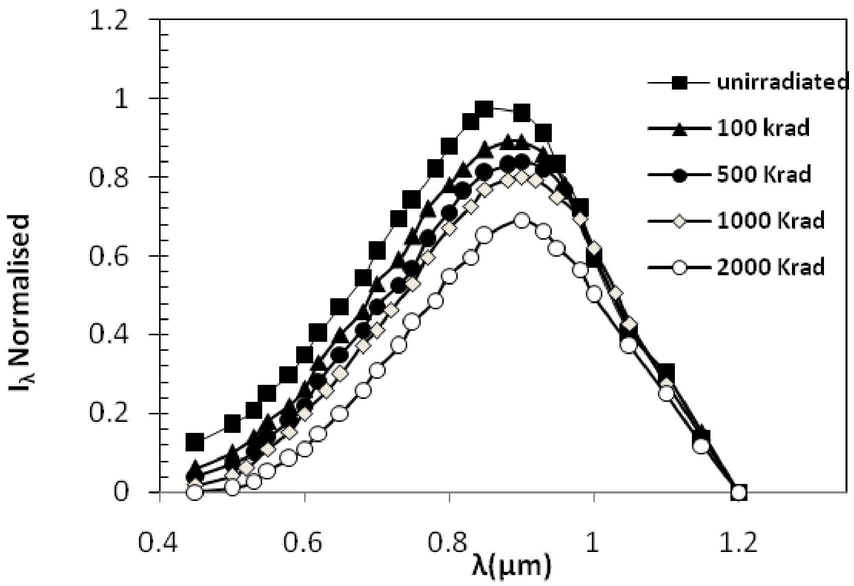

Figure 5. Photo current of silicon solar cells as a function of wavelength with various doses of gamma irradiation

4. CONCLUSIONS

A deterioration of the electric properties of solar cells under gamma irradiation was observed when the gamma dose was increased (1 to 20 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 carriers 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.

According to the spectral photo current results, 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.

ACKNOWLEDGEMENTS
The authors acknowledge the supports given by Islamic Azad university of Ardabil Science and Research Branch for providing research project and Institute of Radiation Problems of Azerbaijan Academy of Sciences for technical assistance in the gamma irradiation work.

References

1. T.M. Razykov, C.S. Ferekides, D. Morel, E. Stefanakos, H.S. Ullal And H.M. Upadhyaya, *Solar Energy* 85(2011) 1580.
2. H.M. Diab, A. Ibrahim, And R. Elmallawany, *Measurement* 46(2013) 3635.

3. M. Alurraldea, M.J.L. Tamasib, And C.J. Brunob, *Solar Energy Materials & Solar Cells* 82 (2004) 531.
4. Heydar Mahdavi and Rahim Madatov, *International Journal of Electrochemical Science* 9 (2014) 1179.
5. A. Vasić, M. Vujisić, B. Lončar, And P. Osmokrović, *Journal of Optoelectronics and Advanced Materials* 9 (2007) 1843.
6. A.Vasic, M.Vujisic, K.Stankovic And B.Jovanovic, *Proceedings of Progressin Electromagnetics Research Symposium Proceedings* (2010) 1199.
7. B. Jayashree, Ramani, M. C. Radhakrishna, A. Agrawal, S. Ahmad Khan, And A. Meulenberg, *IEEE Transactions On Nuclear Science* 53 (2006) 3779.
8. N. Horiuchi, T. Nozaki, and A. Chiba, *Nuclear Instruments and Methods in Physics Research* 443 (2000) 186.
9. T. Pisarkiewicz, *opto-electronics review* 12 (2004) 33.
10. D. Nikolic, K. Stankovic, L. Timotijevic, *International Journal of Photoenergy* Article ID 843174 (2013)
11. A.Vasic, P. Osmokrovic, N. Marjanovic, M. Pejovic, *International Journal of Photoenergy* Article ID 171753 (2013)
12. A. Ali, T. Gouveas, M. A. Hasan, S. H. Zaidi, M. Asghar, *Solar Energy Materials & Solar Cells* 95 (2011) 2805.
13. A. M. Saad, *Canadian Journal of Physics* 80 (2002) 1591.
14. M. Ashry, S. Fares, *Microelectronics and Solid State Electronics* 1 (2012) 41.
15. O. Tuzun, Ş. Altindal, Ş. Oktik, *Renewable Energy* 33 (2011) 286.
16. S.M. Sze, Physics Of Semiconductor Devices, 2nd Edition, Wiley Interscience, Newyork, 1981.
17. Khuram Ali, Sohail A. Khan, And M.Z. Matjafri, *International Journal of Electrochemical Science* 8 (2013) 7831.
18. Ussama A.I. Elani, *Journal of King Saud University* 22 (2010) 9.
19. J. Kuendig, M. Goetz, A. Shah, and E. Fernandez, *Solar Energy Materials and Solar Cells* 79 (2003) 425.
20. P.Sathyanarayana Bhat, A. Rao, H. Krishnan, and G. Sanjeev, Solar EnergyMaterials&SolarCells 120 (2014) 191.
21. M. Imaizumi, S. J. Taylor, T.Hisamatsu, S.Matsuda, O.Kawasaki, *Proceedings Of The 26th PVSC Proceedings, IEEE* (1997) 3.