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Investigation of Electrical Parameters of Gamma Irradiated Photovoltaic Cells [1]

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Abstract

In this study, some electrical characteristics such as current-voltage (I-V), power-voltage (P-V), maximum power (P_{max}), fill factor (FF), short-circuit current (I_{SC}), open circuit voltage (V_{OC}) and power conversion efficiency (η) of silicon based photovoltaic cells have been investigated before and after irradiation. 10 kGy and 30 kGy radiation doses have been applied on cells using a ^{60}Co radioisotope as irradiation source. Radiation dose rates have been decreased the open circuit voltage and short circuit current density and finally affected the performance of the solar cells. This attributed to radiation-produced recombination centers in the energy band gap of structures.

Keywords: Gamma irradiation, photovoltaic, cell efficiency

Gama ile Işınlanmış Fotovoltaik Hücrelerin Elektriksel Parametrelerinin Araştırılması

Öz

Bu çalışmada, ışınlama öncesi ve sonrasında silikon bazlı fotovoltaik hücrelerin akım-voltaj (I-V), güç-voltaj (P-V), maksimum güç (P_{max}), dolum faktörü (FF), kısa devre akımı (I_{SC}), açık devre voltajı (V_{OC}) ve güç dönüşüm verimliliği (η) gibi bazı elektriksel karakteristikleri incelenmiştir. Hücrelere, ^{60}Co radyoizotopu radyasyon kaynağı kullanılarak 10 kGy - 30 kGy radyasyon dozları uygulanmıştır. Radyasyon doz oranları fotovoltaik hücrelerin açık devre voltajını ve kısa devre akım yoğunluğunu düşürerek güneş hücrelerinin performansını etkilemiştir. Bu durum yapıların enerji bandı aralığında radyasyonla üretilen rekombinasyon merkezlerine atfedilmiştir.

Anahtar Kelimeler: Gama ışıması, fotovoltaik, hücre verimliliği

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1. Introduction

The demand for energy resources has increased with the development of technology. There are many energy sources such as fossil fuels, natural gas, solar energy and nuclear energy. Photovoltaic cells are used for generating electricity from solar energy. The studies on using of solar cells as electrical power systems are gained importance. The research, development and commercial studies on silicon solar cells show the importance of photovoltaic cells. Photovoltaic cells such as Si and GaAs are used for applications of ionizing radiation in high-energy physics experiments, medical imaging, electronics or space applications [1-4]. Especially, it is important to investigate the radiation hardness of solar cells that are used as energy sources in space applications. The changes of efficiency on photovoltaic cells can be observed as positive or negative depending on the applied radiation dose such as ^{60}Co gamma rays, electrons, protons and neutrons. In recent years, the effect of gamma radiation on the electrical properties of monocrystalline silicon cells has been investigated by using ^{60}Co radiation source [5 and 6].

In this study, the effects of gamma ray on polycrystalline silicon cell performance have been investigated using a solar simulator. The basic electrical characteristics such as cell efficiency, fill factor, open circuit voltage and short circuit current before and after radiation have been determined using I-V and P-V curves. Experimental results showed that the electrical parameters of photovoltaic cells were changed under different gamma irradiation doses.

2. Material and Method

Commercial polycrystalline silicon cells have used as samples of photovoltaic cell (Figure 1). The current-voltage (I-V) and power-voltage (P-V) characteristics of solar cells have been performed in the light environment using a solar simulator. The solar simulator is special devices that provide near-sunlight lighting. It has characteristic properties that can prepare the controllable environment in laboratory conditions.

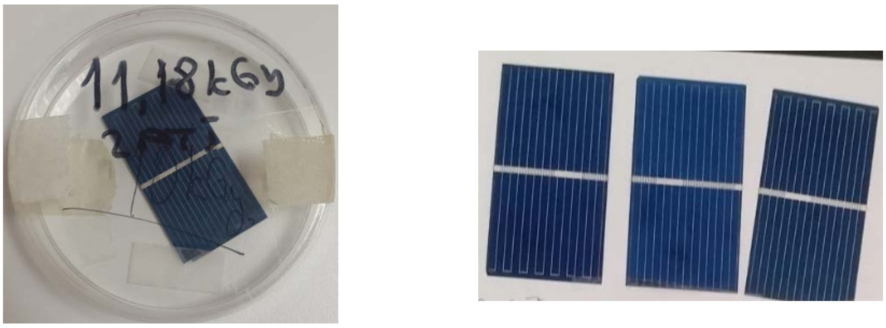

Figure 1. Silicon cells

In Figure 2, the SL-60A-WS solar simulator device is shown that used to determine the solar cell parameters in the Center Research Laboratory Application and Research Center of Giresun University. The light intensity has selected under standard conditions (1000 W / m^2, AM1.5 and 25 ºC).

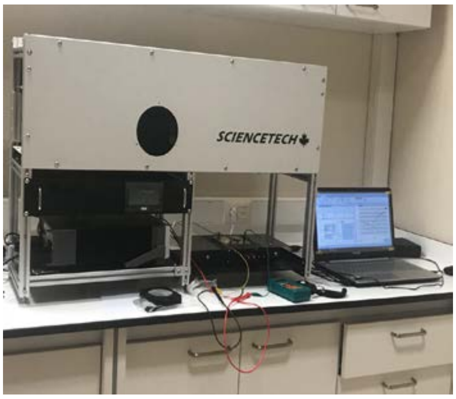

Figure 2. The view of SL-60A-WS solar simulator

The electrical parameters of the solar cells before irradiation have been calculated by using the data obtained from current-voltage (I-V) and power-voltage (P-V) curves. After that, the solar cells have been irradiated at doses of 10 kGy and 30 kGy using ^{60}Co gamma ray source at Turkish Atomic Energy Authority. I-V and P-V measurements and parameter calculations have been repeated after 10 kGy and 30 kGy doses.

3. Results

The electrical parameters of solar cells such as fill factor and efficiency can be extracted from I-V measurements [7]. The fill factor parameter is an express the quality of a solar cell. The fill factor also affects the efficiency of the solar cell and is given as

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

where V_{mp} is the maximum voltage, I_{mp} is the maximum current, V_{oc} is the open circuit voltage and I_{sc} is the short circuit current. The efficiency (η) for a solar cell is given by

$$\eta = \frac{V_{oc}\, I_{sc}\, FF}{solar\ radiation \cdot cell\ area} \quad (2)$$

where FF is the fill factor. Current-voltage (I-V), power-voltage (P-V) and fill factor curves of photovoltaic cell in the light environment before irradiation are shown in the Figure 3. When current-voltage (I-V) graph is examined, it is seen that short circuit current (I_{sc}) and open circuit voltage (V_{oc}) values of the cell are 398,71 mA and 616,00 mV, respectively. When the power-voltage (P-V) graph is examined, the maximum current (I_{mp}) and the maximum voltage (V_{mp}) values are 363,06 mA and 483,3 mV, respectively. The fill factor (FF) was calculated as 71,45% from Equation 1.

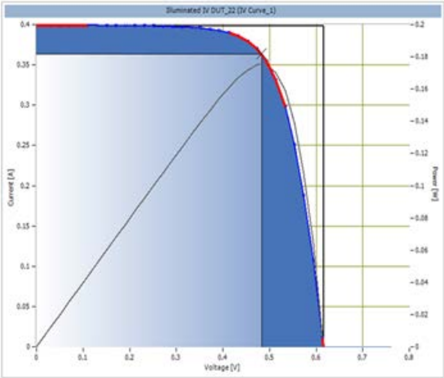

Figure 3. I-V, P-V and FF curves of photovoltaic cell before irradiation

Figure 4 shows I-V, P-V and FF curves of photovoltaic cell after irradiation dose of 10kGy. The measurement results shown that short circuit current (Isc) and open circuit voltage (Voc) values of cell are given a decrease of 310,17 mA and 593,30 mV, respectively. Imp and Vmp values are measured as 279,88 mA and 472,90 mV, respectively. The fill factor has been calculated as 71,92% by using Equation 1.

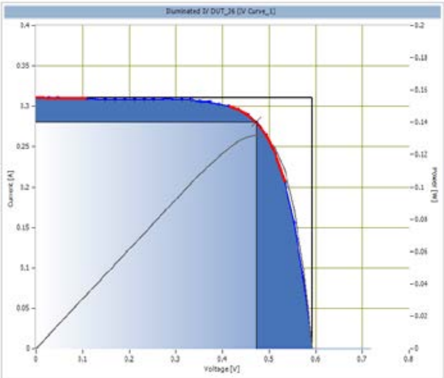

Figure 4. I-V, P-V and FF curves of photovoltaic cell after irradiation dose of 10 kGy

I-V and P-V measurements with 30kGy irradiation dose are given in Figure 5. Experimental data showed that I_{sc} and V_{oc} values were 303.02 m and 589.00 mV, respectively. I_{mp} and V_{mp} values were 272,47 mA and 470,40 mV, respectively. Fill factory value is calculated as 71,81%.

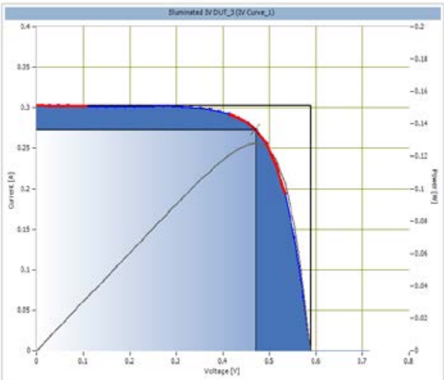

Figure 5. I-V, P-V and FF curves of photovoltaic cell after 30 kGy dose

I-V curves of the photovoltaic cell in the light environment before and after irradiation are given in Figure 6. The experimental result showed that the current and voltage values are decreased, when I-V measurements are performed after irradiation.

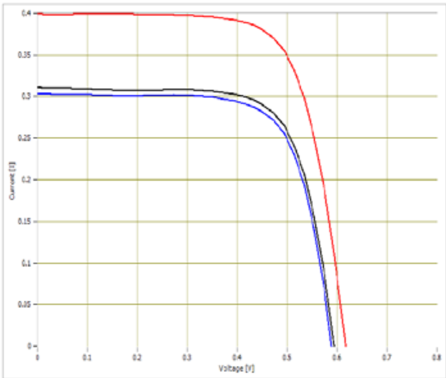

Figure 6. I-V curves of photovoltaic cell under illumination:
Before radiation (red), 10 kGy (black) and 30 kGy (blue)

After irradiation doses of 10 kGy and 30 kGy, the short circuit current values have been reduced by 88.54 mA and 95.69 mA, respectively. The open circuit voltage of solar cell at 10 kGy and 30 kGy irradiation doses are decreased by 22,70 mV and 27,00 mV, respectively. New energy levels generated by radiation in the band-gap range have been reduced the number of minority carriers. This situation has caused a reduction in the short circuit current. Moreover, the radiation applied to the structure has caused a decrease in the open circuit voltage by increasing the number of recombination centers.

The fill factor-dose curves of the photovoltaic cell in the light environment are given in Figure 7. The fill factor of solar cell has been calculated as 71,45% before irradiation. After irradiation doses of 10 kGy and 30 kGy, the fill factor has been calculated as 71,92 % and 71,81 %, respectively. It is seen from Figure 7, there is no significant change in fill factor. Some researchers have declared similar behaviors of fill factor [6].

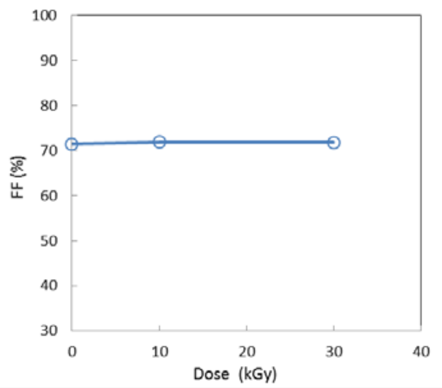

Figure 7. Fill factor-dose curve of photovoltaic cell

The efficiency-dose curves of the photovoltaic cell in the light environment are given in Figure 8. The efficiency of solar cell has calculated as 13.50% from Equation 2 before irradiation. The efficiencies of photovoltaic cells have been calculated after 10 kGy and 30 kGy irradiations as 10.18% and 9.86%, respectively.

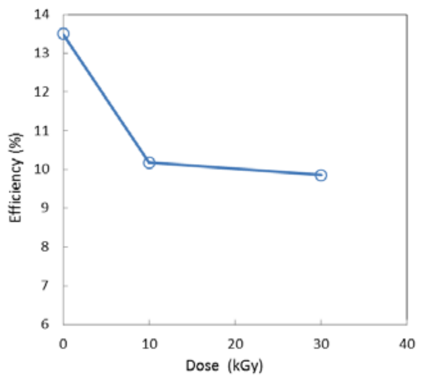

Figure 8. The Efficiency-dose curve of photovoltaic cell

4. Discussion and Conclusion

In this work, the electrical characterization of polycrystalline silicon cells has been investigated before and after gamma irradiation under standard conditions (1000 W / m2, AM 1.5, 25 ºC) by using a solar simulator device. When photovoltaic cells have exposed to gamma rays, the basic electrical parameters have changed. The open-circuit voltage and short-circuit current density of irradiated cell have been decreased compared to before gamma radiated one. Deep interface energy levels generated by ionizing radiation have reduced minority carriers life by trapping their as recombination centers. Thus, they have prevented them from reaching the electrodes. It has negatively affected the electrical characteristics and performance of solar cell. As a result of short circuit current, open circuit voltage and the efficiency of solar cell have changed. On the other hand, the results of our study showed that the silicon based photovoltaic cells can be used in radiation applications such as ionizing radiation detector and dosimeter.

5. References

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Uzun Özet

Teknolojinin gelişmesi ile birlikte enerji kaynaklarına olan ihtiyaç hızla artmaktadır. Ülkemizde de güneş hücresi veya güneş pilleri olarak adlandırılan fotovoltaik hücreler güneş enerjisinden elektrik üretimi için kullanılmaktadır. Bu kapsamda günümüzde, silikon güneş pilleri ile ilgili yoğun araştırma, geliştirme ve ticari alanlardaki çalışmalar fotovoltaik hücrelerin önemini göstermektedir. Güneş pillerinde; monokristal, çoklu kristal, mikrokristal, amorf ve gözenekli gibi çeşitli silikon türleri kullanılır. Silisyum elementi fotovoltaik hücrelerin ana malzemesidir ve üzerine gelen güneş fotonlarını direkt elektrik enerjisine çevirme gibi çok önemli özelliğe sahiptir. Tüm yarıiletken devre elemanları gibi güneş pilleri de iyonize radyasyona duyarlıdır. Uygulanan radyasyon dozuna bağlı olarak fotovoltaik hücrelerin verimlerindeki değişim olumlu ya da olumsuz olarak gözlenebilmektedir.

Buradaki çalışmada Co-60 radyoizotop kullanılarak gama ışınlarına maruz bırakılan fotovoltaik hücrenin elektriksel karakteristikleri incelenmiştir. Gama radyasyonuna maruz bırakılan polikristal Silisyum hücresinin verimindeki değişiklikleri gözönüne alınmıştır. Kullanılan ışık şiddeti standart şartlar altında (1000 W/m2 , AM 1.5 ve 25 ºC) olarak seçilmiştir. Başlangıçta ışınlanmamış (0 kGy) olan Silisyum hücresinin akım-gerilim (I-V), güç-gerilim (P-V) karakteristiklerinden maksimum güç (P_{max}), doluluk faktörü (FF), kısa devre akımı (I_{sc}), açık devre voltajı (V_{oc}), güç dönüşüm verimliliği(η) hesaplanmıştır. Daha sonra sırasıyla 10 kGy ve 30 kGy ışınlamalar için elde edilen sonuçlarla aynı parametreler hesaplanmış ve ışınlanmadan önce ve sonraki durumlar için birbirleriyle kıyaslamalar yapılmıştır. Radyasyon doz oranlarının fotovoltaik hücrelerin açık devre voltajını ve kısa devre akım yoğunluğunu düşürerek güneş hücrelerinin performansını etkilediği gözlenmiştir.