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Gamma Radiation Effects on the Performance of Mono-crystalline Solar Cells

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ABSTRACT

In this study, we present examples of solar cells that were subjected to various levels of ^{60}Co gamma radiation. The solar cells we use are mono-crystalline, which has a stable crystal structure and high efficiency compared to polycrystalline. Prior to and during gamma irradiation, the current-voltage characteristics of monocrystalline silicon solar cells under AM1.5 light conditions and their photon spectral currents were examined. The results of the experiment demonstrate that as the dose of gamma radiation increases, solar cell metrics including open circuit voltage (V_{oc}), short circuit current (I_{sc}), and efficiency (η) drop. The photon spectral current demonstrates that as dose gamma is increased, the current decreases at shorter wavelengths and the defects are primarily produced near the solar cell's surface. Our findings demonstrate the gamma irradiation-induced breakdown of silicon solar cells and the minority carrier lifetime which demonstrates that the minority carrier lifetimes sharply decline with increasing radiation dose.

1. INTRODUCTION

Mono-crystalline silicon solar cells are still the greatest option for photovoltaic solar energy systems [1]. Environmental factors have an impact on the electrical properties of silicon solar cells [2]. Photovoltaic solar cells are subjected to radiation similar to those utilized in satellite and space systems when they are operating [3]. In bulk solar cells, exposure to high-intensity radiation is in the form of gamma rays, neutrons, charged particles, etc [4]. This leads to electrical breakdown and radiation flaws, which significantly degrade the electrical properties of silicon solar panels [5]. The degree of radiation damage determines the solar cells' lifespan and performance [6].

One type of radionuclide that is widely used is ^{60}Co. ^{60}Co is a radionuclide with a fairly long half-life, around 5.27 years [7]. One of the uses of ^{60}Co is for radiotherapy purposes in the medical field, both as an implant and as an external radiation source [8]. Apart from that, other uses in the medical field are the use of tomography benchtop apparatus [9]. In the industrial world, ^{60}Co is widely used, for example for logging, gauging, radiography, and even for scanning the portal detector system to detect the contents of container trucks passing in and out of the port [10]. Due to the many uses of ^{60}Co, we used a 60Co radiation source as a performance test for mono-crystalline solar cells in this study.

The response to electromagnetic radiation of even shorter wavelengths, such as gamma rays [11], is seen in crystalline silicon solar cells, though [12]. Displacement damage and ionization effect are the two types of radiation damage that a silicon solar cell experiences when exposed to gamma rays [13]. Atoms moving from their original positions in the crystal lattice to new locations causes displacement damage [14], which leads to flaws in the crystal lattice of the solar cell [15]. The majority of solar

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cells produce electron-hole pairs as a result of the ionization effect [16]. A solar cell's crystal contains traces of ionized atoms due to electrons escaping from its crystallized atoms [17]. These flaws primarily function as recombination hotspots, which reduce the diffusion length [18] and lifespan of minority carriers while also raising cellular internal parameters [19]. Solar cell internal properties like series resistance (R_S), saturation current (I_0), and ideal factor (n) have a significant impact on solar cell output parameters including maximum output power [20], charge factor, efficiency, short circuit current, and open circuit voltage [21]. It has been established that as the aforementioned solar cell internal parameters grow, output characteristics of the solar cell decrease [22].

The lifetime degradation of minority carriers must be studied in order to examine radiation flaws for various gamma radiation dosages. Minority carriers' lifespan degradation causes changes to the device's attributes [23]. Minority carriers' critical influence on short-circuit currents and open-circuit voltages illustrates how crucial their effective lifetime is to the efficiency of silicon solar cells [24]. In general, solar cells respond well to visible light, which falls within the 400-800 nm wavelength range of the electromagnetic spectrum. In this work, the response of a solar cell to the number of narrow bands of radiation is determined by its spectral properties. In order to better understand solar cell performance, photo-spectral currents are primarily measured [24]. In actuality, red light is absorbed by the majority of the cell while blue light produces electron-hole pairs close to the cell surface. As a result, this study presents changes in the electrical characteristics of silicon solar cell samples subjected to varied dosages of gamma radiation and photo-spectral currents.

2. EXPERIMENTAL METHOD

For the experimental observations in this work, four commercial silicon solar cell samples with identical properties are used. Table 1 displays sample specs. Phosphorus was diffused into a p-type silicon wafer to create the mono-crystalline structure of the solar cell. The four samples were exposed to radiation from a ^{60}Co gamma source with a 1.23 MeV energy. Samples 1, 2,..., and 4 each received radiation dosages of 1, 5, 10, and 20 kGy, repectively, in Advanced Physics Laboratory, Syiah Kuala University, Banda Aceh, Indonesia.

Table 1. Properties of four experimental solar cell samples (before irradiation) Measurement conditions: 1000 W/m^2, AM 1.5, 25ºC

Types of Solar Cells	V_{oc} (mV)	I_{sc} (mA)	P (mW)	FF	η (%)
Mono-crystalline	570	34	14	0.72	14

Using a frequency generator, light diodes, and a Tektronix TDS2012B digital storage oscilloscope, minority carrier ages of solar cell samples were measured before and after gamma irradiation. The light diode was connected to the generator and the solar cell sample was evenly exposed to the light diode pulse. The stored minority carriers cannot abruptly fall to zero when the instantaneous generating voltage is zero. An oscilloscope can be used to monitor photocurrent decline, which serves as a lifetime indicator. Fig. 1 depicts the minority carrier lifespan measurement device. This strategy allows the stored minority carriers to remain constant even while the output of the solar cell instantly drops to zero. All samples were examined for current-voltage (I-V) and spectral properties both before and after irradiation. To create distinctive I-V solar cells, the sample is exposed to reflected light from a lamp with an intensity of (according to AM1.5) [25]. Using a spectral response measurement instrument, the spectral properties of solar cells are assessed at wavelengths spanning from 400 nm to 1200 nm [26]. At room temperature, measurements were taken using a very precise measuring device.

Fig. 1. Measurement of the lifetime of minority carriers

4. RESULTS AND DISCUSSION

I-V properties when exposed to gamma radiation

Fig. 2 shows the current-voltage characteristics of the four solar cell samples before and after different gamma radiation dosages under the AM1.5 lighting condition. It is evident that when gamma irradiation increases, the properties of the I-V cells decrease. The fundamental solar cell characteristics, including open circuit voltage (V_{oc}), short circuit current (I_{sc}), fill factor (ff), and efficiency (η) [27], can be deduced from the measurement as shown in Fig. 1.

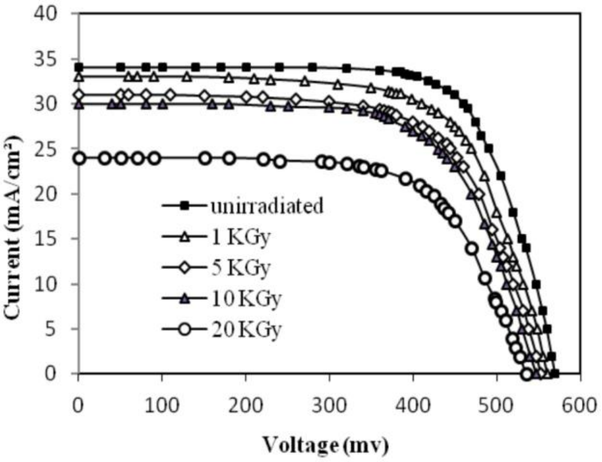

Fig. 2. The I-V properties of silicon solar cells exposed to different levels of gamma radiation

The variations in solar cell characteristics as a function of gamma dosage are shown in Fig. 3. The values acquired before the sample is exposed to radiation are used to standardize the parameters. It was discovered that irradiation has somewhat changed the parameters of solar cells and that the deterioration of those properties relies on the dose of gamma radiation. Fill factors, which occasionally show increasing or rather stable values, show no significant fluctuation [28]. The findings show that gamma radiation significantly lowers the short-circuit current and efficiency while just modestly lowering the open-circuit voltage. Table 2 shows the specific parameters of gamma radiation-induced degradation on solar cells.

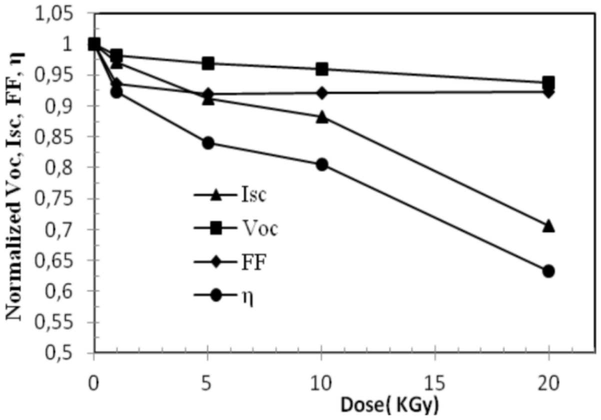

Fig. 3. The relationship between normalized solar cell characteristics and gamma radiation dose

Table 2. Gamma radiation dose-dependent degradation of solar cell characteristics

Solar cell sample	Gamma doses (KGy)	V_{oc} (mV)	I_{sc} (mA/cm^2)	V_{oc} (mV)	I_{sc} (mA/cm^2)	FF	η (%)
Monocrystalline silicon	0	570	34	450	31	0.72	13.9
	1	560	33	440	29	0.67	12.5
	5	552	31	420	27	0.66	11.3
	10	547	30	420	25.9	0.66	10.9
	20	535	24	407	21	0.66	8.5

The lifetime of minority carriers has a significant impact on short-circuit current and other fundamental solar cell characteristics change in response to gamma radiation [29]. The average time of a minority carrier can remain in an excited state following the formation of an electron-hole before recombining is known as the lifetime of a solar cell's minority carriers [30]. Radiation-induced flaws that primarily serve as recombination locations can affect the longevity of minority carriers. Fig. 4 shows how minority carrier lifetimes of silicon solar cell samples changed as a function of dose both before and after gamma irradiation.

For the examination of solar cells, the minority carrier diffusion length is a more useful parameter. The electron-hole recombination point increases with increasing gamma radiation dosage, which causes an increase in minority carrier trapping concentration. The electrical characteristics of the solar cell are decreased as the lifetimes of minority carriers decrease.

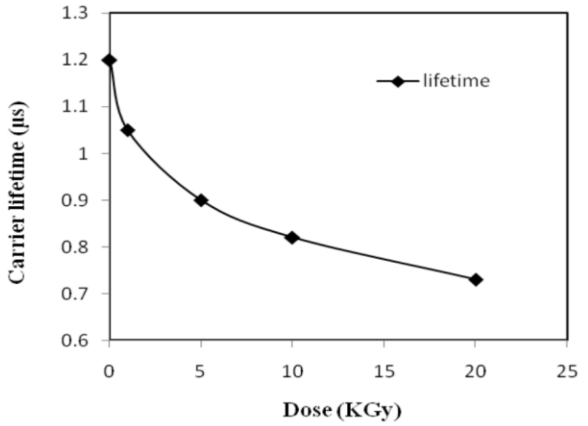

Fig. 4. The lifetime of minority carriers as it varies with different gamma irradiation dosages.

Spectral photocurrent

The modification of photo-spectral current on a sample silicon solar cell, I(λ), in response to gamma radiation is shown in Fig. 5. As can be seen, solar cells that are not exposed to radiation have the maximum photocurrent values across the whole wavelength range, while photocurrent values fall as the gamma radiation dose increases [31]. The findings indicate that the sample photocurrent production has degraded significantly for the lower wavelength region but not for the higher wavelength range [32]. This indicates that the impact of gamma radiation impacts on silicon solar cells and manufacturing flaws are more pronounced in regions near the cell surface [33]. The solar cell is also susceptible to radiation damage after being subjected to high dose of gamma radiation (20 kGy).

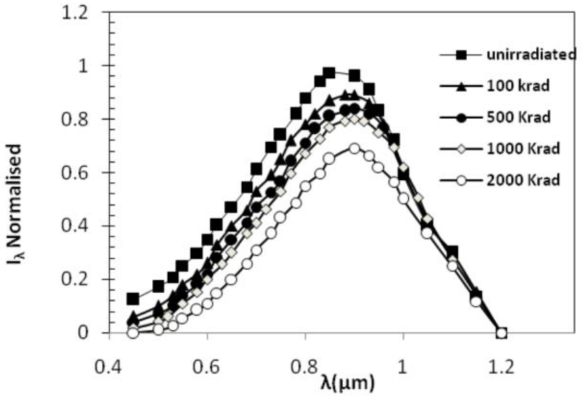

Fig. 5. The photocurrent of a silicon solar cell as a function of wavelength and gamma radiation at different doses

Another research has looked at the efficiency and characteristics of solar cells in diverse environments [34]. The study demonstrates that efforts are being made to improve silicon solar cells through development, innovation, and novel device concepts in order to reduce their cost, increase their efficiency, and make them more competitive with traditional optoelectronic devices [35]. The experimental data inferred from in this study further demonstrate that solar cells outperform more traditional optoelectronic components like photo-transistors and photodiodes, even in terms of dependability in a gamma radiation environment.

5. CONCLUSION

It was shown that as the gamma dose grew, the electrical characteristics of solar cells exposed to the radiation are decreased (1 to 20 kGy). In contrast to the fill factor, which occasionally shows an increase or a very stable value, gamma radiation significantly reduces Isc while only slightly lowering V_{oc}. The lifespan of the minority carriers is primarily responsible for the decrease in short-circuit current and other essential metrics. Reduced minority carrier lifespan lowers the characteristics of the solar cell because it is subject to radiation-induced flaws that primarily operate as recombination hotspots. The findings on photo-spectral current show that following gamma irradiation, the majority of the cell's performance is lost at low spectral wavelengths, indicating that the production flaws caused by gamma radiation occur close to the cell's surface.

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AUTHOR CONTRIBUTION

Soni Prayogi carried out experiments and measurements of the characterization of solar cells under the influence of radioactive material radiation. Zainuddin participated together as an observer and data analyst. Soni Prayogi and Zainuddin both contributed as main contributors to this paper. All authors read and approved the final version of the manuscript.

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