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RESEARCH ARTICLE

QUALITY PERFORMANCE OF MONO - CRYSTALLINE SILICON SOLAR CELLS IN ^{137}CS-BASED RADIATION RICH ENVIRONMENT.

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Abstract

This work explores the effects of ^{137}Cs γ-irradiation on the Photovoltaic parameters of a mono-crystalline silicone solar cell. A suitable (light source- solar cell) geometry was instrumented. It consists of a halogen lamp of 500W power and 100mW.cm-2 light intensity, and a mono-crystalline silicone solar cell with an active area of 10cm×5cm. At room temperature, the forward bias (I(current)-V(voltage)) and (P(power)-V(voltage)) characteristics were determined under illumination, before and after irradiation with different ^{137}Cs gamma-exposure doses; 280mR, 560mR and 837mR, respectively. The results demonstrated that gamma-exposure doses have a significant effect on the photovoltaic parameters and it controls the quality and performance of the solar cell. The open circuit voltage (V_{oc}), short circuit current (Isc), maximum output power (Pm), fill factor (FF) and efficiency (η) are found to be decreased with gamma exposure doses.

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Introduction:-

Solar cells are the basis of nearly all space power systems. The space market for commercial communications as well as military and scientific applications is driving a rapid development of new solar cells technologies to provide increased power.

However, the space environment is a dynamic mixture of different space energetic particles, these particles enter the space solar cells and cause defects as they pass through and are slowed down. These defects can lead to a possible degradation of the electrical performance of the solar cell, which could have negative impact on both the financial and environmental aspects of the solar cell application.

Radiation in space is generated by particles emitted from a variety of sources both within and beyond our solar system. Radiation effects from these particles can not only cause degradation, but can also cause failure of electronic and electrical system in space vehicles or satellites,[1]

This work, studies the basic physical mechanisms of the interactions of ionizing radiation with solar cells targeting the radiation-induced effects generated by gamma ray photons of ^{137}Cs gamma ray source. These defects are to be evaluated by carrying out experimental measurements and to evaluate the Direct Ionizing Radiation Damage by evaluating the I-V characteristics of the solar units under test.

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Theoretical aspects of radiation damage

Irradiation damage in solar cells are mostly caused by atomic displacement which break the periodic lattice structure of the semiconductor material and interfere the movement of the minority carriers resulting in decrease of carrier lifetime. These irradiation atomic displacements can also affect the properties of other electrical devices such as batteries, detectors and communication instruments which are equipped for a space mission [2]. For this reason the radiation induce effect has gained a lot of interests in studying the degradation of this kind of materials and devices including solar cell.

Different radiations like gamma rays, protons, electrons etc produce defects in solar cells .these defects mainly act as recombination centers as a result of which the diffusion length of carriers is decreased [2]. When a photon is incident on silicon, there are three phenomena's that may occur :

1. The photon passes through silicon.
2. The photon is reflected back .
3. The photon is absorbed which can either produce heat or produce electron hole pairs . This happens only in the case when the energy of the photon is larger than the band gap of silicon.

When a photon is absorbed, it gives its energy to the electron in the crystal lattice .this electron is present in the valance band and it is unable to move because it is tightly bound in covalent bonds. The photon gives energy to this electron and excites it to the conduction band where it is free to move .in this way, a hole moves through the lattice. In short when photons are absorbed by semiconductors mobile electron-hole pairs are generated. [3]

Radiation Damage In Silicon

It has been assumed that the radiation damage in silicon is proportional to the energy deposited into the displacement interactions (NIEL hypothesis), [4].

The displacement damage cross section D(Ep) expresses the relative displacement efficacy of an impinging particle p with energy Ep, taking into account the various type of interactions between the particle and the silicon atom. The displacement damage cross section is defined by [5]:

$$D(E_P) = \sum_i \sigma_i(E_P) \int_{E_{R\min}}^{E_{R\max}} d\, E_R\, f_i(E_P, E_R) P(E_R) \quad \text{(1}$$

The function fi describes the distribution of the recoil atom with energy ER and P(ER) is the Lindhard partition function of the energy loss in non-ionizing processes by a recoiling nucleus of energy ER. The lower bound of the integral corresponds to the minimum energy required to displace a silicon atom from the lattice and the upper limit is determined by the maximum energy transferred.

The gamma displacement cross-sections for energies up to 14 MeV have been calculated in various materials at two values of displacement threshold energy (24 and 40 eV), [6]. Three types of gamma ray interactions with materials were considered, the photoelectric effect, Compton scattering and pair production. Therefore, the total gamma displacement cross-section consists of three components representing the sum of cross-sections for three interactions;

$$\sigma_\gamma^T(E_\gamma) = \sigma_\gamma^{PE}(E_\gamma) + \sigma_\gamma^{CS}(E_\gamma) + \sigma_\gamma^{PP}(E_\gamma) \quad \text{(2)}$$

Where $E\gamma$ is the gamma incident energy and the superscripts PE, CS, and PP represent photoelectric effect, Compton scattering, and pair production, respectively.

In this work the employed ^{137}Cs gamma source possess an energy of 0.662 MeV , which falls in the range of energies (0.1–10 MeV) within which Compton scattering is predominant . This fact suggests that most of the electrons are produced as a result of Compton Effect.

Instrumentation

A photograph for the light source-solar cell geometry considered for measuring the photovoltaic output parameters of the solar cell is shown in (Fig 1).

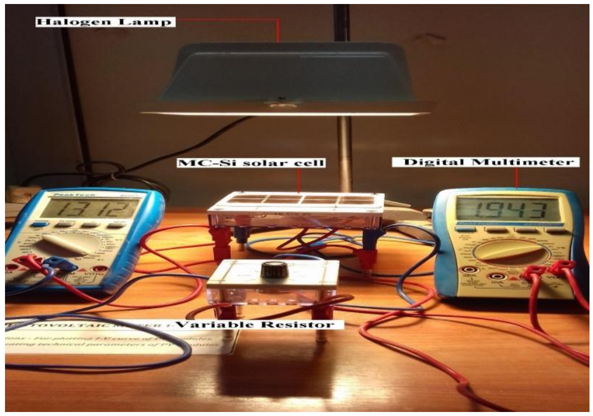

Fig 1:-A photograph for the (light source-solar cell) geometry considered for measuring the photovoltaic output parameters of the solar cell.

The solar cell under test was a commercial mc-Si solar cell with an active area of 10cm×5cm manufactured by Leybold [7] .The employed light source was a 500 W halogen lamp., the light source was fixed at y=20 cm above the active surface area of the solar cell. The halogen lamp bulb is inexpensive, uncomplicated and convenient to operate and require only easy power supply units. The halogen lamp bulb is widely used in solar beam experiments (SBE) for solar simulator applications because it provides a very stable and smooth spectral output [8]. The light source intensity was measured to be 100 $mW.cm^{-2}$.. The light intensity was measured using a pyranometer type HT303N of sensitivity $19.8\mu V/W.m^{-2}$, connected to a solar systems analyzer type HTSolar300.

For γ-ray irradiation, a ^{137}Cs γ-ray source of activity 1mCi and energy of 0.662 MeV was utilized. Two digital multimeters were used to record the output voltage and current while varying the value of a variable resistor (0-1KΩ).

Experimental approach

The forward bias I(current)-V(voltage) characteristics of mc-Si solar cells, before and after gamma ray irradiation, were measured at room temperature for different periods of time. The light source was used to uniformly illuminate the solar cell under test and the measurements were performed within 15 minutes in room temperature. The variable resistor R was set to its maximum value (1KΩ) and both the current (I) and the voltage (V) were recorded. At R=1KΩ, within our measurement conditions, the voltage will approximate the open-circuit value V_{oc}. The resistance was then decreased in steps. Both I and V were recorded for different settings, including the short-circuit current I_{sc} corresponding to R=0. At this point, the light source was turned off and the ^{137}Cs γ-source was located at the y=5cm above the active area of the Si solar cell. The cell was irradiated for 1hr, 2hrs and 3hrs. The corresponding exposures were calculated to be 280mR, 560 mR and 837 mR, respectively. At the end of each exposure time, the ^{137}Cs γ-source is removed and the light source is turned on. The data for I and V including I_{sc} and V_{oc} were recorded following the measurements procedure before ^{137}Cs γ-ray irradiation.

The I-V characteristics, before and after ^{137}Cs γ-irradiation were used to determine the point of maximum power (V_{mp}, I_{mp}) and calculate the fill factor FF. At this point, the output power values including the maximum output values (P_{mp} V_{oc} I_{sc} FF) were calculated and P(power)-V(voltage) characteristics were generated.

On the basis of the I-V characteristics, Solar cell parameters like short circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and efficiency (η) can be calculated. The fill factor (FF) is a key performance parameter for solar cells and can be expressed as;

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} \quad (3)$$

Where V_{mp} and I_{mp} are the voltage and the current at a maximum power point, and V_{oc} and I_{sc} are the open circuit voltage and short circuit current respectively [9]. The efficiency (η) for a solar cell is given by;

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (4)$$

Where I_{sc} is the short circuit current, V_{oc} is the open circuit voltage and P_{in} is the incident light power.

Results and Discussion:-

Using the data obtained in [6], the total displacement damage cross section of silicon for photons is presented in (Fig 2).

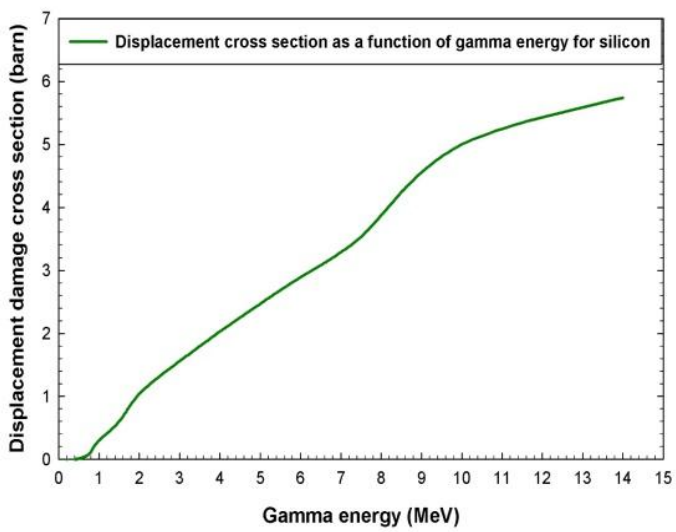

Fig 2:-Displacement damage cross section as a function of gamma energy for silicon

According to Fig 2 the displacement damage cross section for silicon increases proportionally with gamma photon energy. The higher the gamma photon energy the greater the displacement damage is caused.

Effects of illumination of ^{137}Cs γ-ray irradiation on the I–V and P-V characteristics

The forward bias I-V characteristics of the mc-Si solar cell, before and after various ^{137}Cs γ-ray exposure doses; 280 mR, 560 mR and 837 mR, were measured at room temperature at different periods of time and shown in Table 1 and Fig 3. In comparison to the voltage V_{mp} and current I_{mp} values before ^{137}Cs γ-ray irradiations, the V_{mp} values after irradiation were deteriorated by approximately 0.4% ,2.9% ,9%, respectively, while the I_{mp} values were deteriorated by 7.9%, 10.1% and 13.3%, respectively. The variation of the output power with voltage; (P-V) characteristics are reported in Table 1 and Fig 4. As shown, in comparison to the output power values before ^{137}Cs γ-ray exposure doses, the P_{mp} values after irradiation were deteriorated by approximately 8.3%, 12.8% and 21.1%, respectively.

The results reported in Fig 3 and Fig 4 in one hand, re-confirm the deterioration of the I-V and P-V characteristics of the solar cell due to increasing of gamma exposure values and on the other hand demonstrate the feasibility of our proposed (light source-solar cell) geometry.

Table 1:-The illuminated I-V ; P-V characteristics of mc-Si solar cell irradiated with 0.662 MeV ^{137}Cs photons at various doses collectively**.**

Condition	Parameters		
Pre irradiation	I_{mp}	V_{mp}	P_{mp}
	0.937753	0.5401944	0.506569
After irradiation	I_{mp}	V_{mp}	P_{mp}
^{137}Cs (Dose 1) 280 mR	0.863672	0.53807927	0.464724
^{137}Cs (Dose 2) 560 mR	0.842181	0.52443833	0.441672
^{137}Cs (Dose 3) 837 mR	0.812643	0.49155533	0.399459

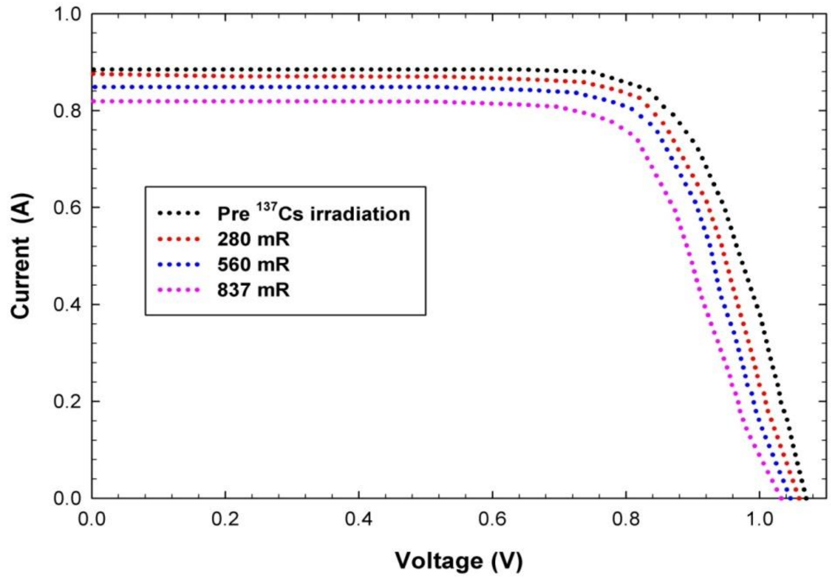

Fig 2:-The illuminated I-V characteristics of mc-Si solar cell irradiated with 0.662 MeV photons at various doses collectively.

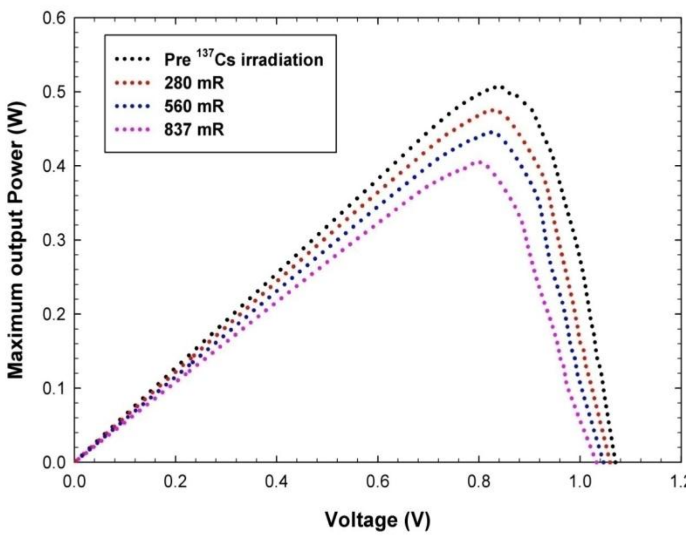

Fig 3:-The illuminated P-V characteristics of mc-Si solar cell irradiated with 0.662 MeV photons at various doses collectively.

Effects of illumination of ^{137}Cs γ-ray irradiation on V_{oc}, I_{sc}, FF and η

The variations of mc-Si solar cell photovoltaic parameters; open circuit voltage (V_{oc}) and short circuit current (I_{sc}) with respect to gamma exposure doses are reported in Table 2 ,beside those for fill factor (FF) and efficiency (η)). All parameters under investigation were normalized to the values obtained before ^{137}Cs γ-ray irradiations. It is clear that the degradation of mc-Si solar cell photovoltaic parameters is dependent on the gamma exposure doses; 280 mR, 560 mR and 837 mR. As shown in Table 2, The V_{oc} and I_{sc} values were deteriorated by approximately 0.9%, 1.6% and 2% for V_{oc}, and 2%, 5% and 10.9% for I_{sc}, respectively.

As reported in Table 2, the FF values were deteriorated by approximately 5.5%, 6.8% and 9.7% respectively. while the η values deteriorated by 7.1% for exposure dose 280mR, 11.7% for exposure dose 560mR and 20.2% for exposure dose 837mR. The results re-confirmed the deterioration effect of ^{137}Cs γ-induced displacement damage on the photovoltaic parameters of the mc-Si solar cells.

Table 2:-Variation of normalized V_{oc} I_{sc} FF and η with ^{137}Cs γ- exposure doses

Condition	Parameters			
Pre irradiation	$\mathbf{V_{oc}}$	I_{sc}	FF	**η**
	1.0000	1.0000	0.506569	0.001
After irradiation	$\mathbf{V_{oc}}$	I_{sc}	FF	**η**
^{137}Cs (Dose 1) 532 mR	0.9910	0.9800	0.478514	0.000929
^{137}Cs (Dose 2) 1064 mR	0.9843	0.9502	0.472234	0.000883
^{137}Cs (Dose 3) 1596 mR	0.9800	0.8912	0.457373	0.000798

Conclusions:-

This work discusses the gamma-induced defects in Silicon-based solar power systems. The experimental methods are used to investigate the impact of ^{137}Cs gamma ray photons on the electrical properties of Silicon-based solar power systems.

The results confirmed the significant impact of ^{137}Cs γ-induced displacement damage on photovoltaic parameters of mc-Si solar cells. As the ^{137}Cs γ- exposure doses are increased; 280mR, 560 and 837 mR, a deterioration of the electric properties of mc-Si solar cell was observed.

The V_{mp} values were decreased by 0.4%, 2.9%, 9% respectively, while I_{mp} values were deteriorated by 7.9%, 10.1% and 13.4%, respectively. Consequently, the maximum output power values were deteriorated by approximately 8.3%, 12.8% and 21%, respectively. Moreover the V_{oc} and I_{sc} values were deteriorated by approximately 0.9%, 1.6% and 2% for V_{oc}, and 2%, 5% and 10.9% for I_{sc}, respectively. Furthermore the FF values deteriorated by 5.5%, 6.8% and 9.7%. while the η values deteriorated by 7%, 11.7% and 20.1% respectively. the results are in good agreement with the available literature.

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