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On the variation of photovoltaic parameters of mono-crystalline silicon solar cell under 1.25 MeV ^{60}co γ-irradiation

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ABSTRACT

This work explores the effects of ^{60}Co 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-V) and (P-V) characteristics were determined under illumination, before and after irradiation with different ^{60}Co γ-exposure doses; 532mR, 1064mR and 1596mR, respectively. The results demonstrated that γ-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 (I_{sc}), maximum output power (P_m), fill factor (FF) and efficiency (η) are found to be decreased with gamma exposure doses.

1. Introduction

Mono-crystalline silicon (mc-Si) solar cell is a part of silicon solar cell family and one of the first developed and mostly used solar cells because it has a number of advantages like low maintenance cost, high reliability, noiseless and eco-friendly (Cuce et al., 2013; Wen et al., 2012; Singh and Ravindra, 2012). Conventional mc-Si solar cells generally exhibit good spectral response to visible radiation, which occupies the 400-800 nm wavelength region of the electromagnetic spectrum.

However, mc-Si solar cells are extremely sensitive to high-level radiation such as ^{60} Co γ-ray photons. Several studies have reported the degradation of photovoltaic parameters for mc-Si solar cells under ^{60} Co γ-irradiation (Tuzon et al., 2008; Scharf, 1960, Junga and Enslow, 1959). These facts have added a new member to the group of radiation sensitive components important in military and civilian applications. In this work, measurements were carried out to re-investigate the ^{60} Co γ-induced effects on the output photovoltaic parameters of a mc-Si solar cell using suitable (light source-Solar cell) geometry.

2. Gamma ray displacement damage

The passage of gamma rays through matter produces electrons and secondary photons in the material. Most of the electrons are produced as the result of the Compton Effect (Junga and Enslow., 1959). Pair production and the photoelectric effect are negligible in the range of photon energies with which we are concerned; 1.25 MeV (Kwon and Motta, 2000). Thus the displacement damage caused by the1.25MeV ^{60}Co γ-rays comes about from energized electrons which are produced within the solar cell by means of Compton Effect.

These γ-induced electrons have a spectrum of energies ranging upward to 0.8 MeV (Statler, 1971) and transfer energy to a lattice atom through an electron-atom scattering event. Atoms are bound to lattice sites and a certain amount of energy must be imparted to the atom in order to displace it from its normal site and create a vacancy-interstitial pair. In silicon, this minimum energy E_d is about 13eV (Loferski and Rappaport, 1958). The energy E_t which an electron must have in order to impart energy E_d to the struck atom is related to E_d by the following (Seitz and Koehler., 1958):

$$E_d = \frac{2m_e}{M_2}\frac{E_t}{m_e c^2}(E_t + 2m_e c^2);$$

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For silicon, E_t, is about 0.14MeV.

3. Gamma displacement cross-section

The photon-induced energetic electrons can be produced from Compton scattering, photoelectric effect and pair production. For gamma ray energies below 0.1 MeV, the dominant mode of interaction of the gamma ray with material is the photoelectric effect. Pair production is energetically possible only if the gamma ray energy exceeds 1.02 MeV, which corresponds to twice the rest mass energy of an electron (Kwon and Motta, 2000). Compton scattering is the predominant mechanism at intermediate gamma ray energies, ranging from 0.1 to 10 MeV in metals. In Compton scattering, the incoming gamma ray is deflected by a certain angle with respect to its incident direction, and thus imparts a portion of its energy to the electron at rest, which then becomes the recoil electron (Kwon and Motta, 2000).

In this work, the employed ^{60}Co gamma source possesses an average energy of 1.25MeV, which falls in the range of energies (0.1-10MeV) within which Compton scattering is predominant. This fact suggests that most of the electrons are produced as a result of Compton Effect. Compton scattering displacement cross-sections in silicon as a function of gamma energy at displacement threshold energy of 24 eV are presented in Fig. 1. The data was taken from (Kwon and Motta, 2000).

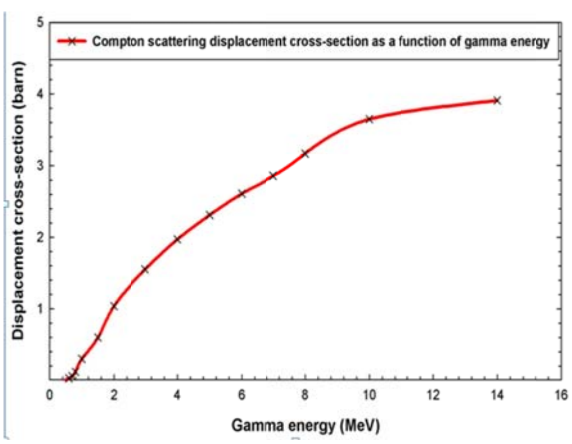

Fig. 1: Displacement cross-sections in silicon for the Compton scattering at the displacement threshold energy of 24 eV

4. Effect of displaced atoms on solar cell performance

The permanent damage in the solar cells materials is caused by collisions of the incident radiation particles with the atoms in the crystalline lattice, which are displaced from their positions. These defects degrade the transport properties of the material and particularly the minority carrier lifetime (Hovel, 1975; Messenger and Ash, 1986; Alexander, 2003; Horiushi, 2000). Photovoltaic parameters of silicon solar cell such open circuit voltage (V_{oc}), short circuit current (I_{sc}), maximum output power (P_m), fill factor (FF) and efficiency (η), strongly depend on minority carrier life time (Yukahe, 2014). And several authors (Alurralde et al., 2004; Imaizumi et al., 1997; Guseynov et al., 2007) have reported that a decrease in the minority carrier life time reduce the electric properties of solar cells.

This work examine a suitable (light source-solar cell) geometry and describes a series of measurements carried out to characterize the ^{60}Co γ-induced displacement damage on a mc-Si solar cell in terms of variation of mc-Si solar cell photovoltaic parameters; V_{oc}, I_{sc}, P_m, FF and η with respect to ^{60}Co γ-ray exposure doses.

5. Instrumentation

Schematic diagram for the circuit considered for measuring the photovoltaic output parameters of the solar cell under test is shown in Fig. 2. A photograph for the light source-solar cell geometry was shown in Fig.3. The solar cell under test was a commercial mc-Si solar cell with an active area of 10cm×5cm manufactured by Leybold. The employed light source was a 500 W halogen lamp. In a Cartesian system of reference where the y-axis coincides with the solar cell axis and is directed upwards, the light source was fixed at y=20 cm above the active surface area of the solar cell. This will provide a 90^0 incident angle for photons of the light source (Fig. 3).

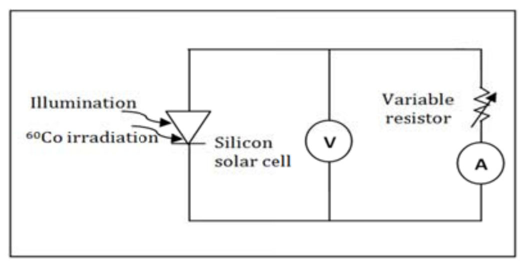

Fig. 2: Schematic diagram for the circuit utilized for current measurements

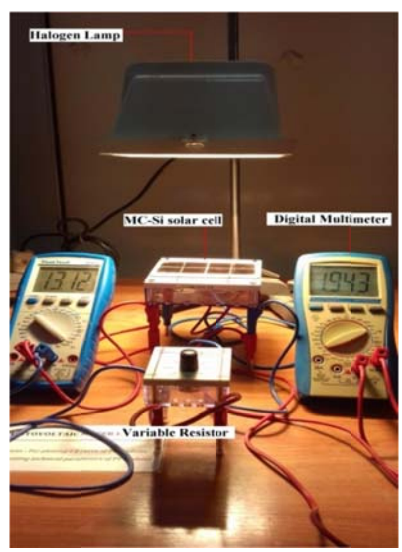

Fig. 3: A photograph for the (light source-solar cell) geometry

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 (Irwan et al., 2015). The light source intensity was measured to be 100 $mW.cm^{-2}$. This value simulates AM1.5 solar radiation over the active area of the solar cell (Khan et al., 2010). The light intensity was measured using a pyranometer type HT303N of sensitivity 19.8μV/$W.m^{-2}$, connected to a solar systems analyzer type HTSolar300. For γ-ray irradiation, a ^{60}Co γ-ray source of activity 1mCi and average energy of 1.25meV was utilized. Two digital multimeters were used to record the output voltage and current while varying the value of a variable resistor (0-1KΩ).

6. Measurements procedure

The forward bias I-V characteristics of mc-Si solar cell, before and after ^{60}Co γ-ray irradiation, were measured at room temperature. The light source was used to uniformly illuminate the solar cell under test and the measurements were performed within 15 minutes in room temperature. It is important to carry out the measurements within a short time scale (~0.25 % hour) to avoid elevating the cell temperature, as this will result in a decrease of V_{oc}, with a relative reduction in light conversion efficiency of about 0.4% K^{-1} (Van Overstraeten and Mertens, 1986). 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 ^{60}Co γ-source was located at the y=5cm above the active area of the Si solar cell. The cell was irradiated for 1 hr, 2hrs and 3 hrs. The corresponding exposures were calculated to be 532 mR, 1064 mR and 1596 mR, respectively. At the end of each exposure time, the ^{60}Co 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 ^{60}Co γ-ray irradiation. The I-V characteristics, before and after ^{60}Co 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-V) 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;

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

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 (Bhat et al., 2014). The efficiency (η) for a solar cell is given by;

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (2)$$

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

7. Results and discussion

7.1. Effects of illumination and 60Co 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 ^{60}Co γ-ray exposure doses; 532 mR, 1064 mR and 1596 mR, were measured at room temperature and shown in Fig. 4. In comparison to the voltage V_{mp} and current I_{mp} values before ^{60}Co γ-ray irradiations, the V_{mp} values were deteriorated by approximately 1.5% for all exposures, while the I_{mp} values were deteriorated by 4.2%, 2.5% and 6.8%, respectively. The variation of the output power with voltage; (P-V) characteristics are reported in Fig. 5. As shown, in comparison to the output power values before ^{60}Co γ-ray exposure doses, the P_{mp} values were deteriorated by approximately 9%, 7.4% and 13.6%, respectively. The results reported in Fig. 4 and Fig. 5, 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.

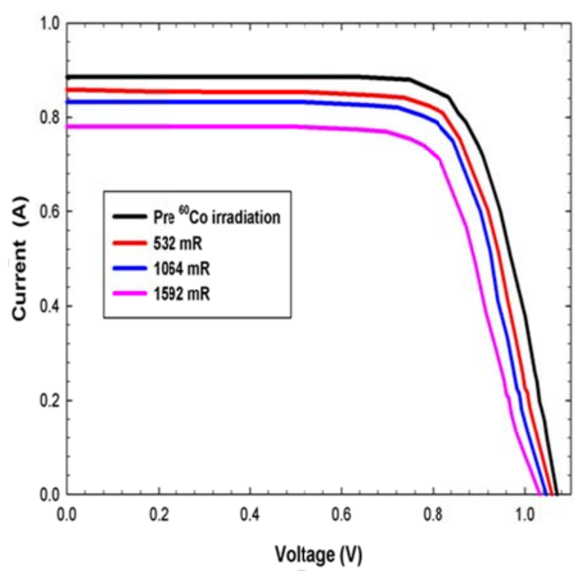

Fig. 4: The illuminated I-V characteristics of mc-Si solar cell irradiated with 1.25 MeV photons at various doses, underAM1.5 illumination condition

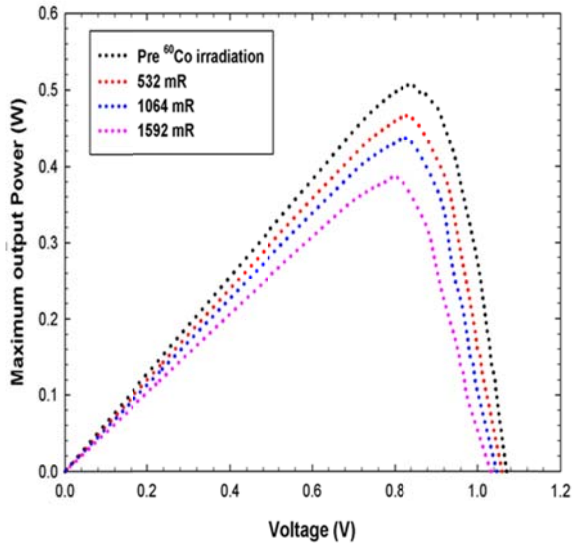

Fig. 5: The illuminated P-V characteristics of mc-Si solar cell irradiated with 1.25 MeV photons at various doses, underAM1.5 illumination condition

7.2. Effects of illumination and 60Co γ-ray irradiation on Voc, Isc, 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 Fig. 6. While those for fill factor (FF) and efficiency (η) are reported in Fig. 7. All parameters under investigation were normalized to the values obtained before ^{60}Co γ-ray irradiations. It was found that the degradation of mc-Si solar cell photovoltaic parameters is dependent on the gamma exposure doses; 532 mR, 1064 mR and 1596 mR. As shown in Fig. 6, The V_{oc} and I_{sc} values were deteriorated by approximately 1.5%, 0.7% and 0.85% for V_{oc}, and 3%, 3.15% and 6.7% for I_{sc}, respectively.

As reported in Fig. 7, the FF values deteriorated by approximately 3% for all ^{60}Co exposure doses, while the η values deteriorated by 7.7 for exposure dose 532mR and approximately 7% for the rest of two exposure doses. The results re-confirm the deterioration effect of ^{60}Co γ-induced displacement damage on the photovoltaic parameters of the mc-Si solar cells.

8. Conclusions

This work characterizes the ^{60}Co γ-induced displacement damage on mc-Si solar cells in terms of variation of photovoltaic parameters. The forward bias (I-V) characteristics and the rest of measurements were carried out at room temperature. 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 commercial mc-Si solar cell with an active area of 10cm×5cm. For irradiation, a ^{60}Co γ-ray source of activity 1mCi and average energy of 1.25meV was utilized. The results confirmed the significant impact of ^{60}Co γ-induced displacement damage on photovoltaic parameters of mc-Si solar cells.

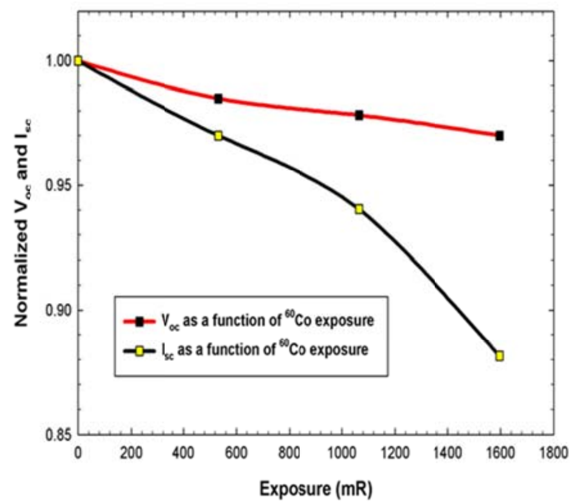

Fig. 6: Variation of normalized V_{oc} and I_{sc} with ^{60}Co γ-exposure doses

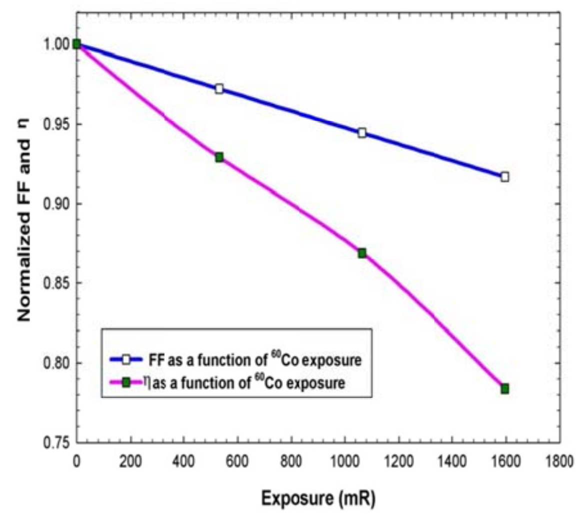

Fig. 7: Variation of normalized FF and η with ^{60}Co γ-exposure doses

As the ^{60}Co γ- exposure doses are increased; 532mR, 1064 and 1596 mR, a deterioration of the electric properties of mc-Si solar cell was observed. The V_{mp} values were decreased by approximately 1.5% for all exposures, while I_{mp} values were deteriorated by 4.2%, 2.5% and 6.8%, respectively. Consequently, the maximum output power values were deteriorated by approximately 9%, 7.4% and 13.6%, respectively. The V_{oc} and I_{sc} values were deteriorated by approximately 1.5%, 0.7% and 0.85% for V_{oc}, and 3%, 3.15% and 6.7% for I_{sc}, respectively. On the other hand, the FF values deteriorated by approximately 3% for all ^{60}Co exposure doses, while the η values deteriorated by 7.7 for exposure dose 532mR and approximately 7% for the rest of two exposure doses. In terms of degradation of photovoltaic parameters for the mc-Si solar cell under ^{60}Co γ irradiation, the results are in good agreement with the available literature.

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References

Alexander DR (2003). Transient ionizing radiation effects in devices and circuits. IEEE Transactions on Nuclear Science, 50(3): 565-582.

Alurralde M, Tamasi MJL, Bruno CJ, Bogado MM, Plá J, Vázquez JF and Kreiner AJ (2004). Experimental and theoretical radiation damage studies on crystalline silicon solar cells. Solar Energy Materials and Solar Cells, 82(4): 531-542.

Bhat PS, Rao A, Krishnan S, Sanjeev G and Puthanveettil SE (2014). A study on the variation of c-Si solar cell parameters under 8MeV electron irradiation. Solar Energy Materials and Solar Cells, 120: 191-196.

Cuce E, Cuce PM and Bali T (2013). An experimental analysis of illumination intensity and temperature dependency of photovoltaic cell parameters. Applied Energy, 111: 374-382.

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

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

Hovel J (1975). Semiconductors and semimetals. Academic Press, New York, USA.

Imaizumi M, Taylor SJ, Yamaguchi M, Hisamatsu T, Matsuda S and Kawasaki O (1997). Analysis of the spectral response of silicon solar cells irradiated with high fluence electrons/protons. In Twenty-Sixth IEEE conference on Photovoltaic Specialists: 983-986.

Irwan YM, Leow WZ, Irwanto M, Amelia AR, Gomesh N and Safwati I (2015). Indoor Test Performance of PV Panel through Water Cooling Method. Energy Procedia, 79: 604-611.

Junga FA and Enslow GM (1959). Radiation effects in silicon solar cells. IRE Transactions on Nuclear Science, 6(2): 49-53.

Khan F, Singh SN and Husain M (2010). Effect of illumination intensity on cell parameters of a silicon solar cell. Solar Energy Materials and Solar Cells, 94(9): 1473-1476.

Kwon J and Motta AT (2000). Gamma displacement cross-sections in various materials. Annals of Nuclear Energy, 27(18): 1627-1642.

Loferski JJ and Rappaport P (1958). Radiation damage in Ge and Si detected by carrier lifetime changes: damage thresholds. Physical Review, 111(2): 432-439.

Messenger GC and Ash MS (1986). The effects of radiation on electronic systems. Van NostrandReinhold, New York.

Scharf K (1960). Photovoltaic effect produced in silicon solar cells by X-and gamma rays. Journal of Research National Bureau of Standards, 64A(4): 297-307.

Seitz F and Koehler JS (1956). Displacement of atoms during irradiation. Solid State Physics, Seitz F and Turnbull D (Eds), Academic Press, New York, USA, 305-448.

Singh P and Ravindra NM (2012). Temperature dependence of solar cell performance—an analysis. Solar Energy Materials and Solar Cells, 101: 36-45.

Statler RL (1971). Radiation damage and annealing of lithium-doped silicon solar cells. In the Fourth Annual Conference on Effects of Lithium Doping on Silicon Solar Cells: 91-98

Tüzün Ö, Altındal Ş and Oktik Ş (2008). Effects of illumination and 60 Co γ-ray irradiation on the electrical characteristics of porous silicon solar cells. Renewable Energy, 33(2): 286-292.

van Overstraeten R and Mertens RP (1986). Physics, technology and use of Photovoltaics. Taylor & Francis, Oxfordshire, UK.

Wen C, Fu C, Tang J, Liu D, Hu S and Xing Z (2012). The influence of environment temperatures on single crystalline and polycrystalline silicon solar cell performance. Science China Physics, Mechanics and Astronomy, 55(2): 235-241.

Yukahe TC (2014). Studying photovoltaic parameters of the aging silicon solar cells by thermal annealing. International Journal of Advanced and Applied Sciences, 1(6): 1-6.