Effect of radiation on electrical characteristic measurement of the fabricated CdTe / P-Si heterojunction Solar Cell

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***Abstract*— *The electrical and photovoltaic properties of CdTe/p-Si heterojunction solar cells prepared by evaporation cooting on a single-crystal p-type silicon substrates are examined, under (100) mw/cm^2, 25℃. The best fabricated cell shows an open-circuit voltage before irradiation γ is(0.59V) and after irradiation γ is (0.565 V). The short-circuit current density before irradiation is (35 mA/cm^2) and after irradiation is(30 mA/cm^2). The fill factor before irradiation γ is (54.5 %) and after irradiation γ is (53 %). The conversion efficiency (active area) before irradiation γ is(11.2%) and after irradiation γ is(5.1%) .was observed during two-hour illumination test and after storing the cell in air for three months. The illumination is from the CdTe side (front wall) .The cells are analyzed using I-V and P-V measurements, with focus on the influence of the time solar cell radiation, light intensity illumination and effective dose of γ-radiation, which play a crucial role to improve the solar cell efficiency. γ-irradiation campaign with different doses has been carried out on a series 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*— *n-CdTe/ P-Si Cells Performance, γ-radiation Effects, Electrical and Photovoltaic Characteristics solar cell, gamma radiation, spectral photo current.

I. 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, RS, saturation current, I0 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].

Conventional single-junction semiconductor solar cells only effectively convert photons of energy close to the semiconductor band gap Eg as a result of the mismatch between the incident solar spectrum and the spectral absorption properties of the material [6]. Photons with energy Eph smaller than the band gap is not absorbed .Photons with energy Eph larger than the band gap is absorbed, but the excess energy E_{ph}- E_g is not used effectively due to thermalization of the electrons. Several routes have been proposed to overcome these fundamental spectral losses that can account from as much as 50%. All these methods or concepts, which are referred to as Third Generation(3G) photovoltaic[7], concentrate on a better exploitation of the solar spectrum, e.g., intermediate band gaps[8], quantum dot concentrators[4] and down- and up-converters[9, 10].

II. EXPERIMENTAL WORK

The substrate materials are two-inch diameter (100) – oriented, p-type silicon wafers with a resistivity of (1.4-2.0 Ω.cm), corresponding to a doping density of (4-6) x10^{15} cm^{-3}. These wafers were etched using CP_4 etching solution for (2) min,(CP_4 etching solution is prepared by adding 20mL of HF acid to 30 mL. Acetic acid and 60 mL concentrated HNO_3). After etching, the Si-wafers were washed for 5 min by distilled water, and then by ethyl alcohol.

The CdTe: In film were evaporated onto the Si-wafers by using Cooting unit Edward type (E306A), Evaporation was carried out at pressure(10^{-5} Torr) in vacuum, to coated one side of the Si-wafers by n-CdTe thin film with different thickness. The CdTe thin film side, was over coated by an indium mesh to be used as grid electrode. After the CdTe: In film Coated, the ohmic rear contact was fabricated by vacuum evaporation of Indium silver, and Aluminum electrodes. Then the front electrode was made by evaporating a Al metal grid, through a metal shadow mask. Finally, CdTe/p-Si Heterojunction were annealed for two hours (2H) at 523k (250°C) to complete the Junction formation. Sample irradiation was carried out using a 60Co gamma source model ISSLEDOVATEL manufactured by Russian irradiator and located at NCRRT, Vienna. The dose rate was 910 kGy /100 min and the temperature during irradiation was about 40^oC. Irradiation doses by γ-radiation with different doses (500, 1400, 1900 M Rad).

III. RESULTS AND DISCUSSION

3.1 Electrical and Photovoltaic Characteristics of CdTe/ p-Si Solar Cell

The electrical characteristics of the photovoltaic cells were investigated in the dark and under different bias light conditions. The solar cell parameters, short circuit current density I_{sc}, open circuit voltage V_{oc}, and maximum out putted power (P_m) were determined. During dark I-V measurements, a light-proof cover shields the cell under test. The dark I-V curve is measured in forward and reverse directions as shown in Fig.(1).

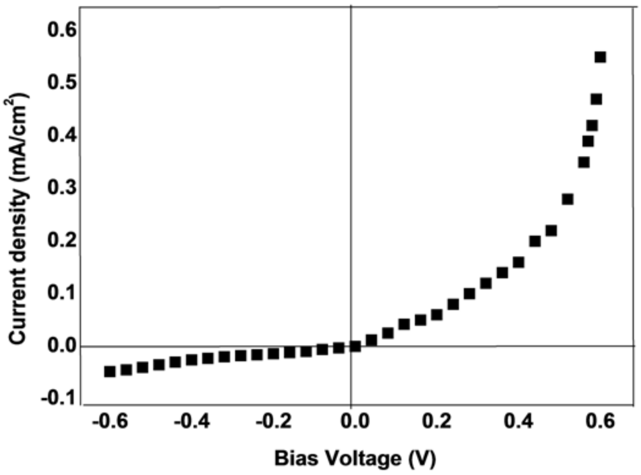

FIGURE 1. CURRENT – VOLTAGE CHARACTERISTIC IN DARK

3.2 Effect of time of radiation on Electrical Performance

We investigated the influence of time of radiation on solar cell characteristics. The time of radiation is a critical factor effecting cell performance. Ionization occurs whenever the alpha particle is sufficiently close to electron to pull it out from orbit though coulomb attraction. Each time this occurs, the alpha loses kinetic energy and is thus slowed. The alpha also loses kinetic energy by exciting orbital electrons with interactions that are insufficient to cause ionization. As it becomes slowed, the alpha has tendency to cause ionization at an increasing rate. As the alpha nears to the end of its track, its rate of ionization peaks and within very short distance, it stops, collects two electrons and becomes helium atom. Since alphas are low in penetration ability, they themselves are usually not hazardous for external exposure, unless the alpha-emitting nuclide is deposited to organism. When internally deposited, alpha particles are often more damaging than most other types of particles because comparatively large amounts of energy are deposited within a very small volume of tissue. Beta particles also cause excitation of external orbital electrons, which in turn leads to the emission of ultraviolet photons. The ultimate fate of a beta particle depends upon its charge. A negatively charged beta particle, after its kinetic energy has been spent, either combines with a positively charged ion, or becomes a "free electron". Positrons, however, have a different fate. In spite of the fact that they dissipate their kinetic energy just like beta particles through ionization and excitation, they cannot exist at rest in the vicinity of the electrons. When a positron has been slowed sufficiently, it will be attracted to the opposite charge of an electron. The interaction of photons (γ-quantums) with matter involves several distinct processes. The relative importance and efficiency of each process is strongly dependent upon the energy of the photons and upon the density and atomic number of the absorbing medium.

Both V_{oc} and I_{sc} are dependent on the time of radiation for all solar cell used. Fig.(2) shows, as the time of radiation (5, 10, 20, 30 min) decrease, the short circuit current I_{sc} and open-circuit voltage V_{oc} over a wide range of illuminated light intensity is observed to be decrease, which is due to the low bulk diffusion length, electrons generated near the rear side of the solar cell have a low probability for collection. Due to the high internal area reflection, the total generation is hardly reduced by time of radiation. But the generation takes place closer to the junction and that will increase the collection probability. It shows that time of radiation best range is ~5 min.. The electrical parameters of the different fabricated solar cells and different radiation source are presented in table (1). These parameters were obtained from (I-V) illuminated characteristics curve as a function of time of radiation.

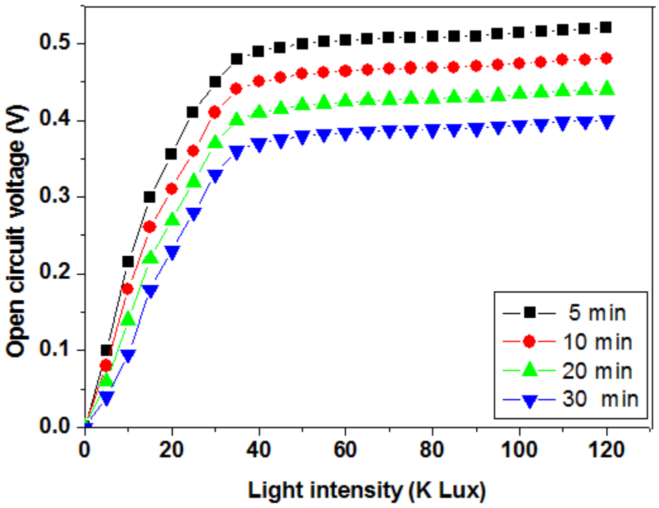

FIGURE 2. OPEN CIRCUIT VOLTAGE CURVE AS A FUNCTION OF LIGHT INTENSITY FOR DIFFERENT TIME OF RADIATION

TABLE 1

ELECTRICAL PARAMETERS OF FABRICATED SOLAR CELLS AS A FUNCTION OF THICKNESS BEFORE AND AFTER γ- β, AND γ IRRADIATION

Time of radition	**Type radiation**	**V_{oc}(mV)**		**J_{sc}(mA/cm^2)**		**F.F(%)**		**η(%)**	
		Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
5 min	γ	490	440	28	23	34.9	48.6	4.8	3.8
	β		420		21		46.2		3.64
	α		400		20		44.5		3.45
10 min	γ	520	505	30	25	45	50.4	6.8	4.5
	β		490		23		47		4.1
	α		480		21		45.8		3.9
20 min	γ	560	530	33	27	51	52.3	9.2	4.8
	β		515		25		49.5		4.5
	α		500		23		47		4.15
30 min	γ	590	565	35	30	54.5	53	11.2	5.1
	β		550		26		52.2		4.9
	α		525		24		50.6		4.7

3.3 Effect of Light Intensity on Electrical Performance

In fact the solar cell with radiation time (5 min) has a much greater spectral response under fluency of light intensity, due to it can absorbed more of the electromagnetic spectrum than the other thinner ones, and thus has the capacity to generate larger currents. Fig.(2) ,a direct result, an increase in short circuit current density as the light intensity increase, while as open-circuit voltage is largely unaffected all over light intensity range and wavelengths incident, which means that, V_{oc} increase up to(20 k Lux) as incident light intensity increase, more than 20 k Lux, Voc stays constant, relatively to the short circuit current density. The electrical parameters of the different fabricated solar cells and different source radiation are presented in table (1). These parameters were obtained from(I-V) illuminated characteristics curve as a function of cell thickness .Finally for most studied solar cells, the short-circuit current density shows a linear relationship with the incident light intensity [11,12]. The open-circuit voltage and fill factor is much weaker dependant on the light intensity[13,14].

3.4 Spectral Response Measurements

Fig.(3) shows results of the spectral response for tested solar cells which were processed with different radiation time (5, 10, 20, 30 min). As it can be seen, for whole cells, the optical properties of solar cells are almost the same trend but with different wavelengths range (i.e), as the solar cell radiation time decrease, the maximum I_{sc} value shifted towards the blue wavelength region. It can be noted that the spectral response at the long wave length decrease with the reduction in the radiation time. Light transmission loss due to an insufficient absorption layer, and carrier recombination loss at the back contact, due to the probable presence of defect at the junction can be considered to be responsible for the total current loss in such thin films.

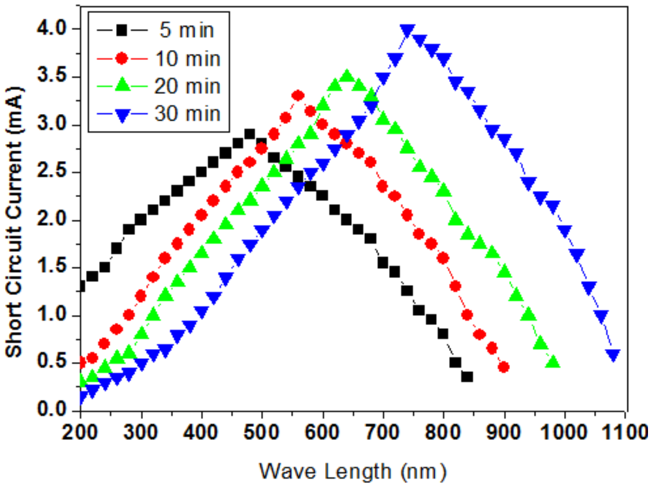

FIGURE 3. SPECTRAL RESPONSE FOR DIFFERENT TIME OF RADIATION

3.5 Effects of Solar Radiation Variation

The above model includes two subsystems: one that calculates the PV cell photocurrent which depends on the radiation and the temperature according to equation (1) [15].

$$I_{ph} = [\ I_{sc} + K_i\ (T - 298)\ ]\ \beta/1000 \qquad (1)$$

where K_i=0.0017 A / °C is the cell's short circuit current temperature coefficient and β is the solar radiation (W/m^2).

As it can be seen from Figs.(4,5) the PV cell current is strongly dependent on the solar radiation. However, the voltage has a 50 mV increase as the solar radiation increased from 400 W/m^2 to 1000 W/m^2.

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 fig. (6). As can be seen, I-V characteristics of cells deteriorated with increasing gamma irradiation. From fig. (6), 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 [16-18].

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 [19-22].

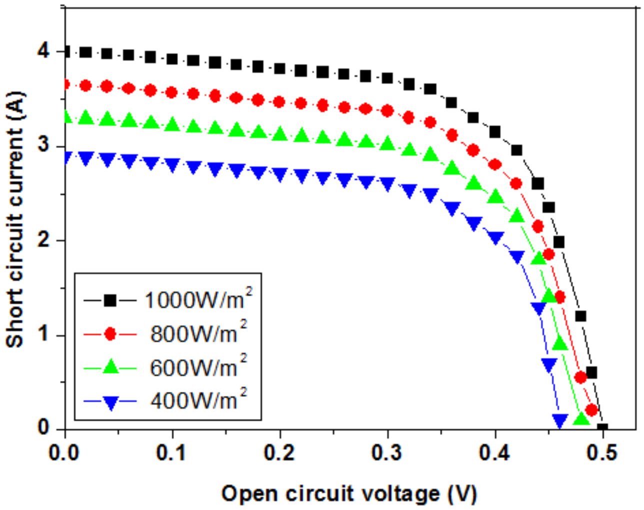

FIGURE 4. I-V CURVES FOR DIFFERENT SOLAR RADIATIONS

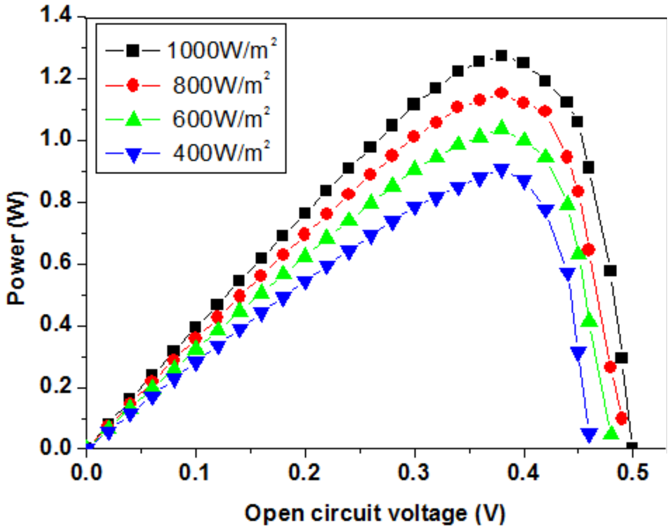

FIGURE 5. P-V CURVES FOR DIFFERENT SOLAR RADIATIONS

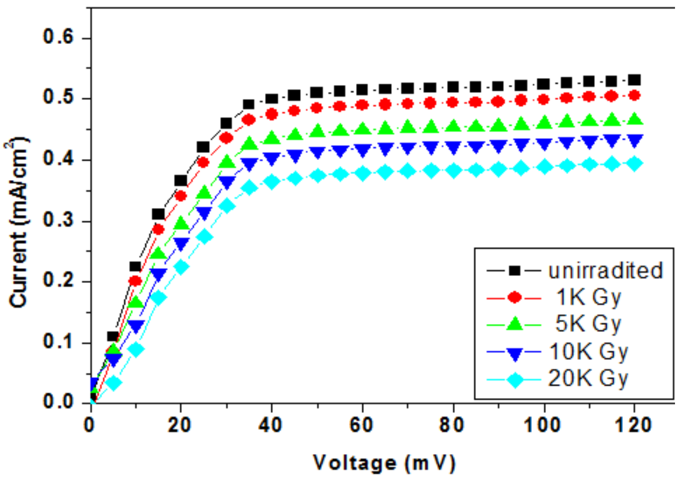

FIGURE 6. THE I–V CHARACTERISTICS OF SILICON SOLAR CELL IRRADIATED WITH VARIOUS DOSES OF GAMMA RADIATION

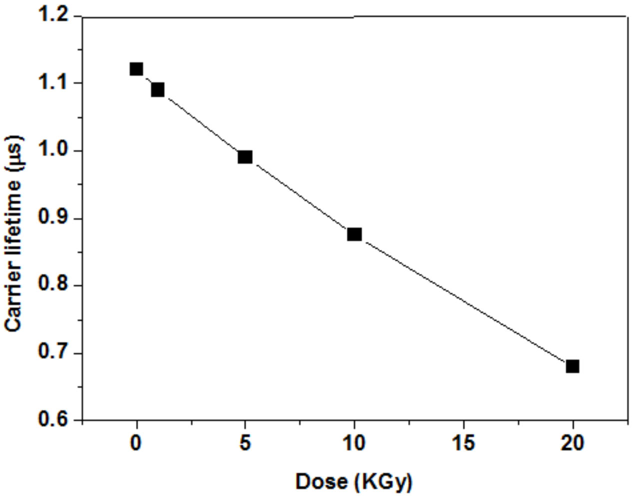

FIGURE 7. THE VARIATION OF MINORITY CARRIER LIFETIME WITH VARIOUS DOSES OF GAMMA IRRADIATION.

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 equation 2:

$$\tau = \Delta n / R \qquad (2)$$

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. (7).

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 [23].

IV. CONCLUSION

The fabrication of CdTe/p-Si Heterojunction by physical thermal evaporation method has been reported .We have investigated the influences of various conditions in the CdTe/p-Si solar cell performance. The effect of cell thick-ness was observed. The thin CdTe/p-Si cell .thickness leads to the typically reduced spectral response in the infrared, and the wave length which has the maximum spectral response was shifted towards the shorter wave length, as the time radiation decrease. In addition the radiation hardness of solar cell performance. The effects of time radiation were observed. The affects of radiation noted a decrease in electrical performance as the radiation dose increase. Parameters such as donor concentration in CdTe, as well as current – voltage, and capacity voltage are described. Efficiency of the best performance solar cell CdTe/ Si approached around 11.2 %.

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.

Of this manuscript must on any scientific group to operate in this area. Must be put solar cells panel far from the radiation sources, particularly the development of gamma rays at each application of solar cells operations in the practical life.

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