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The Laser for Improvement Silicon Solar Cell Efficiency

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Abstract

The purpose of this study is to improve the efficiency of solar cells composed of silicon single crystal. The silicon crystal was subjected to pulsed laser of wave length (1.06 μm) type Nd –Glass under the condition of darkness and illumination.

Electrical properties (I-V) of the irradiated solar cells were studied. The results revealed that the efficiency of some cells is increased after directly irradiated till arrival to steady state. On the other hand some of other cells suffer's reducing in its efficiency after irradiated till arrival to steady state.

Keywords: Solar cell efficiency, Laser, Darkness, illumination, irradiation.

Introduction

The silicon Solar cell structure is one of the simpler semiconductor device structure, consisting in its basic form of a single p-n junction. Semiconductors are materials, which become electrically conductive when supplied of light or heat, but which operate as insulators at low temperature[1]. Silicon (Si) was the first material used for solar cells in space and it has remained the most popular choice ever since due to it's history of reliable performance [2].

All solar cells require a light absorbing material contained within the cell structure to absorb photons and generate electrons via the photovoltaic effect. The conversion process is based on the photoelectric effect discovered by Alexander Bequeral in 1839. The photoelectric effect describes the release of positive and negative charge carriers in a solid state when light strikes its surface [3]. The light sources divide to the ordinary light sources and laser light [4].

Theory

A solar cell is a device that converts solar energy into electricity by the photovoltaic effect. Photovoltaic is the field of technology and research related to the application of solar cells as solar energy.

When light shines on a PV cell, absorbed radiation then creation of electron-hole pairs. When electron-hole pairs are created within the depletion layer, they are separated by the built-in electric field producing either by difference voltage, electric current or both, depending on the external circuit. Hence, the potential difference is limited by the built-in voltage. Which in turn is determined by the energy gap. On the other hand, only photons which have energies larger than the band gap are absorbed in a semiconductor, hence the light generated current decreases with increase in energy gap.

The quantum efficiency refers to the percentage of photons that are converted to electric current [3]. Given by the equation :

$$\eta = [I_m . V_m / A . P_{in}] *100\% \quad \text{......................} (1)$$

Where η : solar cell efficiency.

$I_m . V_m$: the maximum power.

P_{in} : the power of the incident radiation

A :area of the solar cell.

The most important device in almost all photonic applications is the LASER. The laser light source, whose name is based on "light Amplification by stimulated Emission of Radiation" [5]. The laser is a completely different type of light source. As the following characteristics are:-

1- Monochromaticity: One "color" (one wave length) or, more accurately, a very narrow band of wave lengths is emitted by the laser.
2- Collimation: Laser light is emitted in a beam that is quite narrow and stays narrow for wide distance.
3- Power: Power emitted by lasers may be quite high [4].

Successful application of high-power laser pulses in the restoration of ion bombardment - disturbed semiconductor layers has given rise to an explosively growing new scientific and technical method of pulsed modification of the properties of material [6].

Experiment

Irradiated solar cells municipal industrialized of area ($19.625cm^2$) for pulses laser Nd-glass stable (2 pulse) has different energy (E), pulse duration (300µs), focuses (4cm) and wave length (λ) (1.06 µm).

The energy density (flounce) depends on the energy of the laser beam as pulses and the cross sectional area of the laser beam pulses on the sample surface. The flounce can be calculated from the following equation :-

$$F = E / A \quad (2)$$

Where E : laser energy. A : area of the laser beam pulse.

Table (1)

Represent the characteristic (I -V) in the illumination state before and after irradiation.

Sample No.	Cell .NO	$J (J/cm^2)$	$I_{sc}(mA)$	$V_{oc}(Volt)$	$R_s(\Omega)$	$R_{sh}(\Omega)$	F.F	η %
(1)	SK	2.54	36.5	0.47	0.6	3600	0.576	7.19
(2)			38.6	0.49	0.48	1801.8	0.569	7.84
(3)			36.1	0.48	0.5	3600	0.577	7.27
(4)			36.6	0.47	0.53	1801.8	0.579	7.25
(1)	SL	3.82	35.1	0.46	0.29	3600	0.507	5.96
(2)			38	0.47	0.26	1801.8	0.497	6.46
(3)			38.1	0.48	0.24	1801.8	0.493	6.57
(4)			35.5	0.45	3.0	1801.8	0.475	5.53
(1)	SN	5.35	35.5	0.47	0.57	4401.4	0.595	7.23
(2)			39.6	0.47	0.48	1466.7	0.565	7.66
(3)			39	0.49	0.53	4401.4	0.597	8.31
(4)			37.3	0.48	0.46	4400	0.615	8.02
(1)	SO	6.84	35.8	0.47	0.35	2000	0.578	7.08
(2)			37.7	0.46	0.4	4000	0.556	7.02
(3)			37.3	0.47	0.35	2000	0.539	6.87
(4)			34.9	0.46	0.36	2000	0.552	6.45
(1)	SP	9.07	31.6	0.48	0.45	7633.5	0.623	6.87
(2)			36.8	0.47	1.33	3800	0.594	7.49
(3)			34.3	0.49	0.46	2538	0.54	6.7
(4)			33	0.47	0.5	1250	0.555	6.27

Where numbers means the following:- (1): Before irradiation cell by the laser, (2): After directly irradiated cell by the laser, (3): After two week irradiated cell by the laser,(4):After steady state irradiated cell by the laser.

Table (2)

Represent the characteristic (I-V) in the dark state before and after irradiation.

Sample No.	Cell .NO	$J (J/cm^2)$	$I_O(mA)$	n
(1)	SK	2.54	0.16	1.31
(2)			0.065	0.68
(3)			0.12	0.91
(4)			0.085	0.73
(1)	SL	3.82	0.16	0.87
(2)			0.135	0.86
(3)			0.095	0.68
(4)			0.3	1.33
(1)	SN	5.35	0.045	0.74
(2)			0.036	0.72
(3)			0.045	74.0
(4)				0.55

			0.023	
(1) (2) (3) (4)	SO	6.84	0.028 0.035 0.042 0.05	0.69 0.67 0.73 0.96
(1) (2) (3) (4)	SP	9.07	0.15 0.19 0.23 0.25	0.89 1 1.06 1.11

Result and Discussion

1-Characteristic (I-V) in the illumination state.

The efficiency of solar cell (η) can be determined by the parameters, short circuit current (I_{sc}), open circuit voltage (V_{oc}), shunt resistance (R_{sh}), series resistance (R_s) and filling factor (F.F).

The plots in a Figs. (1, 2, 3, 4, 5) revealed that the (I-V) properties were changed under the illumination condition. Where the efficiency of some solar cells were increased while the efficiency of other cells suffer's some reduced depending on using a different energy densities.

When the solar cells subjected to pulses of laser radiation, the efficiency of most cells are increased nearly (10% ± 2%) except the cell coded (SO) where its efficiency reduced nearly 5% as noticed in Table (1). After two weeks irradiated cells, the efficiency of the cells, (SK,SL,SN) were continued increased but the efficiency of cells (SO, SP) were decreased than the irradiated before. After steady state the efficiency of irradiated cells (SN) and (SK) were increased something comparison with irradiated before. While the efficiency of cells (SL,SO,SP) suffer's decreased as mentioned in Table (1).

One can take up the cell (SN) as an example to determined the (I-V) properties before and after irradiated. The (SN) cell was subjected to laser beam of energy density equal to (5.35 J/cm^2) then the (I_{sc}) was increased while the (V_{oc}) remained unchanged. These results due to the (P_{max}) and (η) were increased and associated reducing in values of (R_s), (R_{sh}) and (F.F). After two weeks from irradiation of (SN) cell until arrival to steady state, the values of parameters (I_{sc},V_{oc}, P_{max}, η) were increased and (R_s,R_{sh}) were decreased.

Because of the laser radiation have high energy and short duration of the laser radiation heating and absorption of laser radiation raises the temperature in the solar cell [7].

In a semiconductor material, the process of absorption energy of optical radiation is transferred practically instaneously to the electron subsystem of semiconductor by heating of free carriers, generation of nonequilibrium electron-hole pairs and heating of these pairs [6].

When the lower is energy density value leaves the superficial morphology less modified and reduces the laser impact diameter and crater diameter and induced damage [7], the damages which have small diameter (deep damage) are distributed over the irradiation area [8].This defects give rise to energy levels in the forbidden gap of semiconductors [9] and this levels the increase in short- circuit current density due to depletion layer broadening, decrease in series resistance and the increase efficiency [10]. The open circuit voltage is to connect for the minimization of dark current [11].

For this increased solar cells efficiency from values lower energy densities of the cells (SK, SL, SN) after directly irradiation until arrival to steady state exclusion the cell (SL) where the efficiency increased after directly irradiation and decreased after to the steady state because of the incomplete annealing in some regions due to the spatial inhomgenities in the laser beam in the energy range close to the threshold energy for annealing [10].

When the laser energy increased then the absorption quantity will be increased too because the increase in generated charge carriers from surface [11].

The degradation in the performance of a solar cell due to heating is mainly due to the loss of open-circuit voltage as the reverse saturation current increases and also to some extent on the variation of lifetime of the nonequilibrium minority carriers with temperature. The lifetime of the minority carriers and its temperature variation depend largely on doping of the material and on the various recombination mechanism occurring in the material [12].

The numerical density of the deep damages increases significantly, but the changed of the size damage is very little. Further more when the flounce exceeds approximately twice the threshold of the deep damage, damages covering the large area (shallow damage) are generated [8]. Where energy density value corresponds to a crater and a deep hole formation, for these reasons, the efficiency of the solar cells (SO, SP) will be decreased [7].

2-Characterization (I-V) in the darkness state.

To determine the mechanism of current transfer in a solar cell, one should have to measure the (I-V) characteristics of saturation current(I_o) and ideality factor (n) under the darkness condition before and after irradiated. When n~1 then the generated current as a result of diffusion current. If n~2 then the generated current is a result of recombination current at a depletion region.

One can conclude that a simple changes in values (I_o , n) after irradiation were happened. Then the current moving mechanism was still stability due to diffusion current.

As revealed from the Figs. (6, 7, 8, 9, 10), the Values of (I_o , n) were decreased after arrival to steady state for most subjected cells as mentioned in Table (2), The darkness properties of (I-V) was improvement for this cells because dark current decrease as a result in of efficiency increased.

The minimization of dark current is very important to obtain a high open-circuit voltage and high efficiency. In the same way the larger lifetime, the smaller dark current get a high efficiency of solar cells [1]. A larger lifetime would minimized the rate of recombination [14].

For the cells (SO, SP), when the values (I_o , n) of high energy densities be increased. The efficiency (η) will be decreased because of the generated defect give rise to energy levels in the forbidden gap as a result of increase the rate of recombination.

Conclusion

The following conclusion can be drawn from our consideration of the effect of laser on single crystal silicon solar cell:

1-The efficiency of some solar cells in the illumination state were increased while the efficiency of other cells suffer's some reduced depending on using a different laser energy densities.

2-The darkness properties of (I-V) was improved for some solar cells, One can conclude that a simple changes in values (I_o,n) after irradiation were happened. Then the current moving mechanism was still stability due to diffusion current.

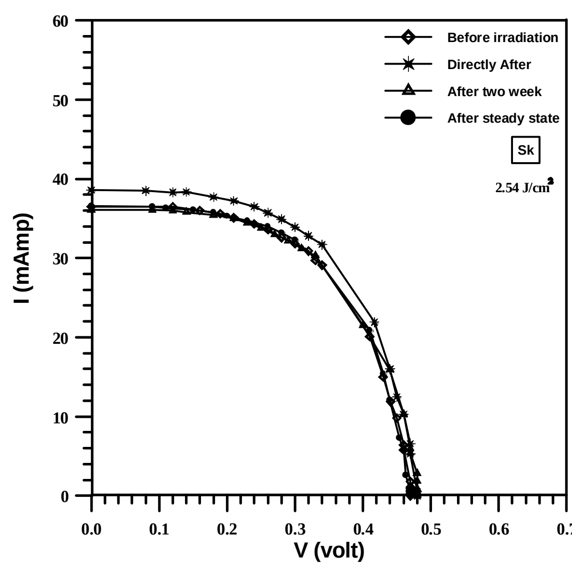

Fig.(1) Represent the (I-V) characteristic in illumination state f or cell (SK) before and after irradiation.

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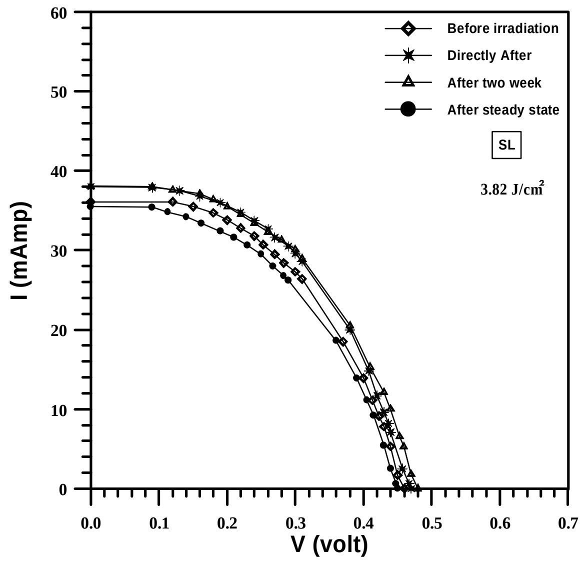


Fig.(2) Represent the (I-V) characteristic in illumination state for cell (SL) before and after irradiation.

Fig.(4) Represent the (I-V) characteristic in illumination state for cell (SO) before and after irradiation.

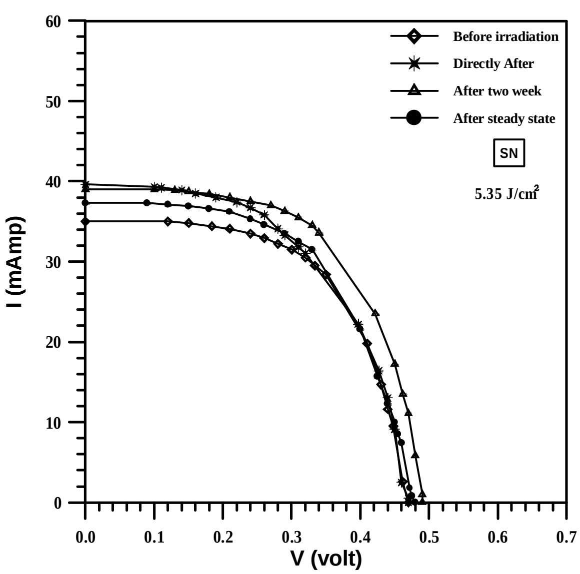


Fig.(3) Represent the (I-V) characteristic in the illumination state for cell (SN) before and after irradiation.

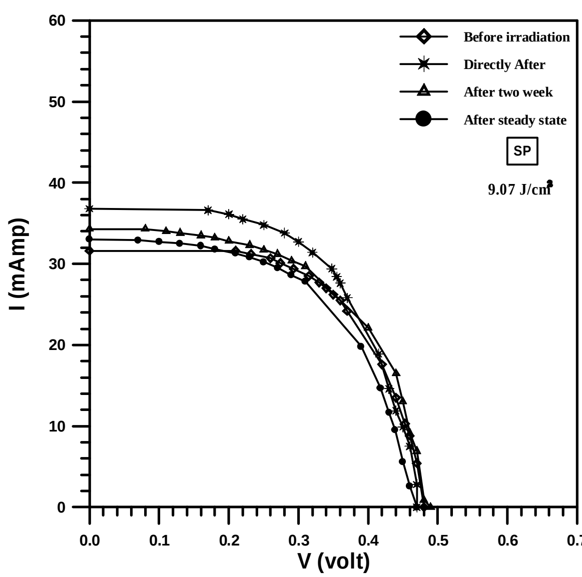
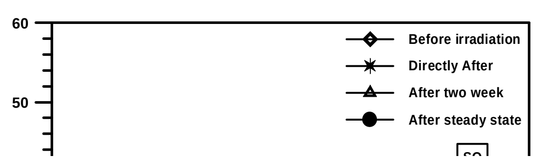


Fig.(5) Represent the (I-V) characteristic in illumination state for cell (SP) before and after irradiation.



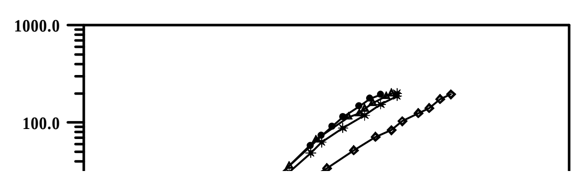


Fig.(6) Represent the (I-V) characteristic in the dark state for cell (SK) before and after irradiation.

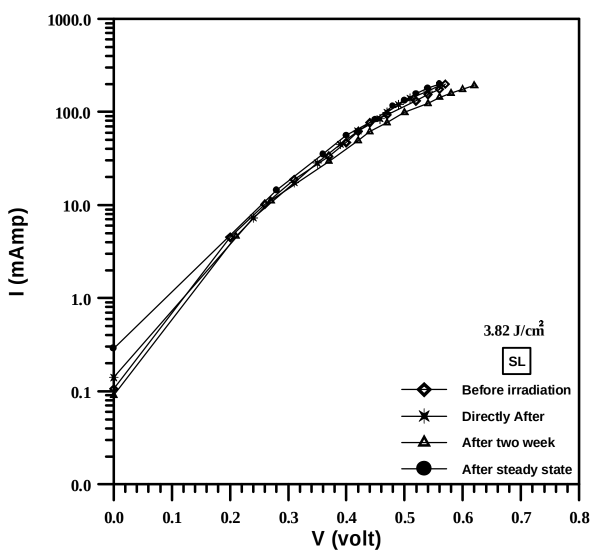


Fig.(7) Represent the (I-V) characteristic in the dark state for cell (SL) before and after irradiation.

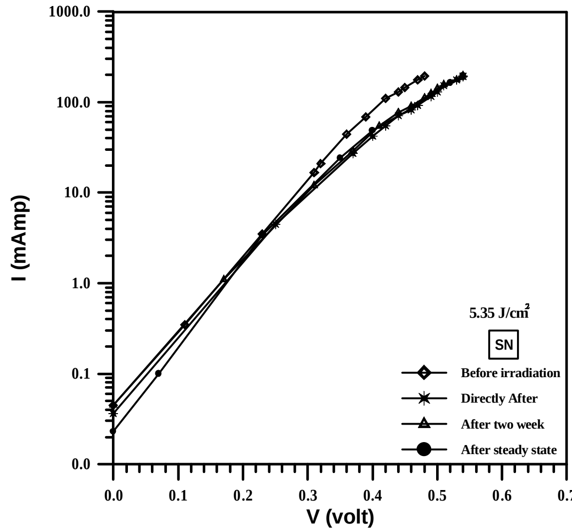


Fig.(8) Represent the (I-V) characteristic in the dark state for cell (SN) before and after irradiation.

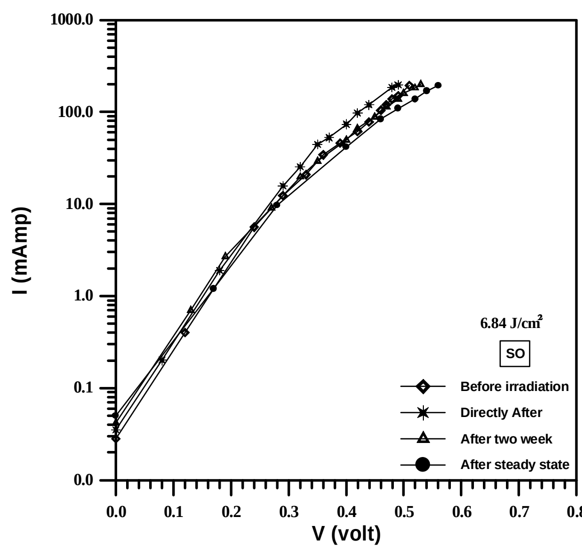


Fig.(9) Represent the (I-V) characteristic in the dark state for cell (SO) before and after irradiation.

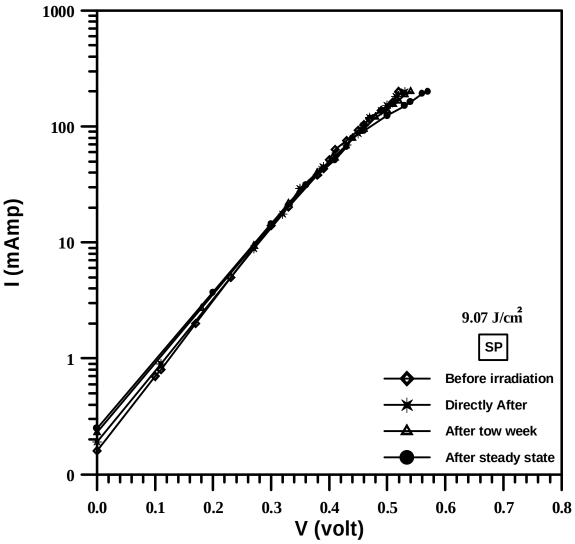


Fig. (10) Represent the (I-V) characteristic in the dark state for cell (SP) before and after irradiation.

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الخلاصة

يهتم هذا البحث بدراسة تطوير كفاءة الخلايا الشمسية السليكونية أحادية البلورة في حالتي الظلام والأضاءة قبل وبعد التشعيع بأستخدام ليزر Nd-glass النبضي ذو طول موجي (1.06 μm) وبكثافة طاقات مختلفة للأشعاع الليزري. من خلال دراسة الخصائص الكهربائية(I-V) للخلايا الشمسية المشععة، تم التوصل الى حدوث ارتفاع في الكفاءة لبعض الخلايا بعد التشعيع مباشرة" وحتى الوصول الى حالة الاستقرار باالأضافة الى حدوث انخفاض في الكفاءة لخلايا اخرى بعد التشعيع وصولا" الى حالة الأستقرار.