

Investigating the Effect of an IR Emitting Element to the Time Constant of Solar Energy Harvesting Device Lifetime

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Abstract

Solar photovoltaic (PV) system is instrumental in provision of sustainable energy in the wake of social and environmental concerns. While research in solar cell efficiency has made great strides and achieved over 40% efficiency. Key concern is however, extending time constant of solar cell lifetime in minimum or no insolation. This emanates from the fact that most of solar cells have solid power storage which runs out under limited insolation reducing reliability of the cells. Improved in PVs high efficiency with flexible and lightweight thin films, would reduce on reliability which can guarantee longest time output in limited insolation. This paper investigated the effect of an infra-red generating element on time constant of a solar cell lifetime when the element is placed adjacent to solar cell. Using a dyesensitized (DSSC) TiO₂ solar cell electrode, maintaining topology, thermal escape mechanism, quantum structure and optical absorption of In(Ga)As quantum dots in a wide gap Al_{0.2}GaAs host material, the study investigated effect of attaching an emitting element on the solar cell lifetime whose findings showed a minimum of 27% increase in power output under low irradiation, while 14% increase in power output was recorded for high irradiation when an IR diode was mounted adjacent to solar cell. The study concluded that standardized IR element adjacent to a solar cell in a PV system significantly stretch a solar cell lifetime and power output.

Keywords: Solar Cell Efficiency, Time Constant, IR Emitting Element, Solar Cell Lifetime.

Introduction

The rapidly increasing energy demand (Madlener & Sunak, 2011; Wolfram, Shelef & Gertler, 2012) and the concerns over environmental degradation (Smil, 2015) resulted from the use of conventional energy sources have opened option for exploring more alternatives sources for energy production. Solar energy is considered as a major renewable sources of energy (Kabir et al., 2018) since it involves zero greenhouse gas emission and zero dependence on fossil fuels (Panwar, Kaushik & Kothari, 2011). The use of solar energy suffers from the challenge of ensuring steady flow of electric power (Li et al., 2011) particularly during the periods of low solar radiation. This has caused system designers to look into the reliability aspects of solar photovoltaic systems (Sharma & Chandel, 2013; Mustafa et al., 2020). One way of minimizing the impact of irregular power supply is by the inclusion of a storage unit so that the surplus energy generated during period of high solar radiation can be stored and utilized later during periods when solar radiation is low or absent. But, according to Schoenung (2011) storage systems using batteries are an expensive proposition. It is of interest to system design engineers to examine just how much is gained in terms of reliability of power delivery at the cost of hardware failure of panel for solar PV systems operated with and without battery storage.

According to Chander et al. (2015), the change in the incident intensity on a solar cell causes change in all solar cell parameters, which include short circuit current (I_{sc}), open circuit voltage (V_{oc}), the fill factor (FF), efficiency (η), diode ideality factor (n), reverse saturation current (I_{rs}), series resistance (R_s) and shunt resistance ($R_{sh} = I/G_{sh}$). These parameters affect the efficiency of the solar cell (Chikate et al., 2015). Chegaar et al. (2013) found that the short circuit current, the photocurrent and the ideality factor increased linearly with the irradiation level intensity, while the open circuit

voltage and efficiency increased logarithmically. According to the study, the fill factor increased slightly for low irradiation intensities, and then it decreased with higher intensities of irradiation. The saturation current increased exponentially, while the series resistance remained invariant and the shunt resistance decreased linearly. It is thus observed that at lower light levels, the shunt resistance impact becomes **increasingly essential**. With reduction in light intensity, the **bias point** and current through solar cell decrease as well, and the solar cell's equivalent resistance can start to approach the shunt resistance. If these two resistances are **equal**, the total current fraction flowing through shunt resistance **increases**, therefore increasing the fractional power loss from shunt resistance. These findings show the importance of taking into account the kind of application of solar cells under low and high illumination intensities.

However, with increased global reliance on solar energy (Solangi et al., 2011), there is need to come up with solar cells that not only have higher efficiency, but also have the ability to stretch their output beyond the irradiation period. Ordinarily, the time constant of a solar cell determines the quasi static condition (Pockett et al., 2015). The magnitude of the time constant depends on various parameters such as the operating point (voltage and current), temperature, irradiance level, minority carrier lifetime, and other semiconductor parameters only to mention the most important ones. This study thus sought to establish if placing an IR element adjacent to the solar cell can reasonably stretch the output life constant hence ensuring reliability of the solar cell under limited irradiation.

Operating solar photovoltaic at lower temperature will increase its lifespan (Siecker, Kusakana & Numbi, 2017). This will reduce module surface area by increasing overall output power. Researchers have proposed and tested several cooling techniques for the panel. One of the most common and effective way to cool PV module is used of water as coolant (Sharma et al., 2018). There are a number of means available to increase solar panel output and efficiency (Stritih, 2016). These factors include solar cell experimental technologies and highest efficiencies where multi-cell gallium arsenide has been found to have 44% efficiency; fill factor (utilization of available surface area); grade of the solar cell; **solar cells glazing** (optical transmissivity) and solar panel orientation. Of the most important according to this study is the **Maximum Power Point Tracking** (MPPT) controller (turns excess power in form of heat into additional charge current). In this study, if this excess power is redirected to the IR emitting element so that the output of the solar cell can be stretched beyond the set period of production when the solar cell receives limited irradiation. This stems from the fact that even though research to increase the lifespan of a solar cell has been extensively done, information on extension of the output time of the solar cell after the irradiation is still scanty.

Methods and Materials

Using two dye-sensitized solar cells (DSSC) using TiO₂ electrodes and germanium

(Ge) mid-wave infrared (MWIR) diode of wavelength 25μm, with index of refraction (n_d) of 4.003, density of 5.33gcm⁻³, coefficient of thermal expansion (CTE) of $6.1 \times 10^6/^{\circ}\text{C}$ and knop hardness of 780, the diode was mounted on the same chip board with one of the solar cell, while the other solar cell was left alone. The reason for choosing InGaP/InGaAs/Ge photovoltaic cells is that they are made to work in concentrated light and their structure is triple junction and the dimensions are 1 cm/1 cm. The short circuit current measured at 190 suns is 2.67A and the open circuit voltage is 2.82 V. No-load voltage (maximum voltage the cell will produce under the current light conditions) and the short-circuit current (maximum current your solar cell can provide) were taken. Next, the

load was swept, while recording voltage and current. For all the observations, resistance was kept constant (same as in the first observation) to enable track changes in the output of the solar cell at the same resistance at different times of day and with/without the IR diode.

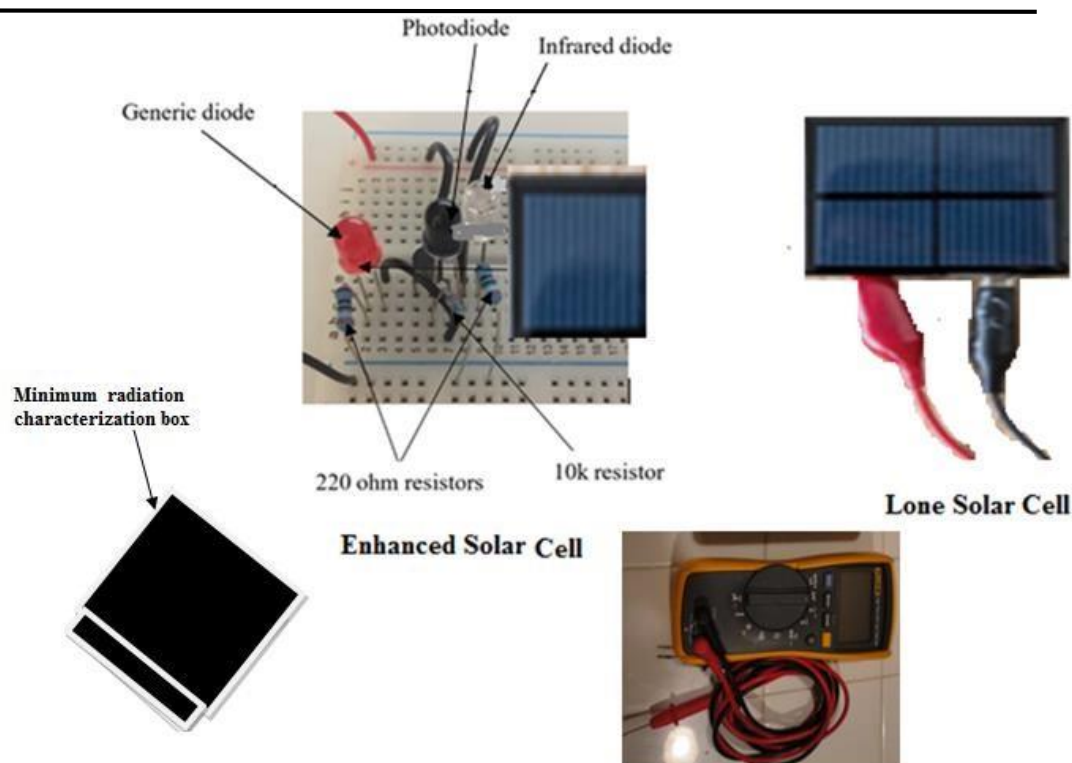


Figure 1: Solar Cell Circuit Assemblage and the Characterization Equipment

The two R_{SH} and single R_S were meant to characterize the solar energy harvesting device for short circuit current (I_{sc}) measured in a sunny day and the open circuit voltage (V_{oc}). For all the observations, resistance was kept constant to enable track changes in the output terminals at different seasons of the day, with and without the IR diode.

The circuit for the characterization is as presented in Figure 2 below

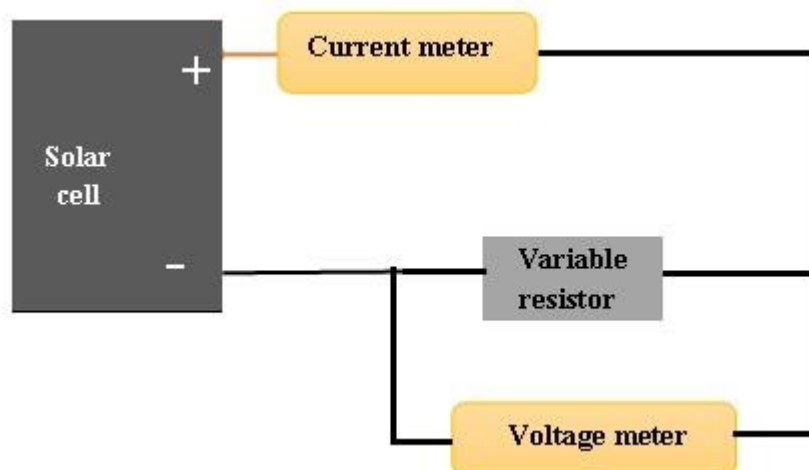


Figure 2: Characterization Circuit of the IR enhanced Solar Energy Harvesting Unit

Two sets of observations were recorded at varied sessions of the day take for comparison of different irradiance. The circuit was used to characterize the lone cell and that which was mounted

adjacent to IR diode. The pair of the experiment conducted between 12 noon and 2 pm for full irradiance and between (5 – 7) pm (EAT) for minimum irradiance.

Results

The experiment was conducted to determine the voltage and current produced by the solar cell at different resistance levels for high irradiance level. The power output was then calculated for the high irradiance.

Table 1: T-I/V Characteristics of IR Enhanced Solar Cell

	Time/Minutes	$V_{oc}(V)$	$I_{sc}(\mu A)$
0	30.21	2.29	
1	29.17	3	
	3	28.12	4.25
	5	27.09	4.51
	7	27.03	6.48
	11	26.99	10.5
	17	26.84	12.8
	27	26.77	14.5
	37	26.63	19.7
	51	25.44	21.4
	57	24.02	22.8
	60	20.99	29.2
	63	19.75	30.4
	67	18.41	31.3
	69	18.36	32.5
	73	17.22	35.8
	77	16.19	36.1
	81	13.15	36.9

87	10.09	37.6
93	8.06	37.9
97	9.74	38.3
101	7.12	38.5
107	5.61	39
111	4.09	39.2
115	3.32	39.5
121	2.71	42
125	2.56	42.9
129	2.11	43
137	2.96	45.2
143	2.48	45.9
157	2.37	56
180	0.8	57

From the results of Table 1, a graphical presentation of time against current (I_{sc}) and potential (V_{oc}) was made during the high irradiation with an IR diode

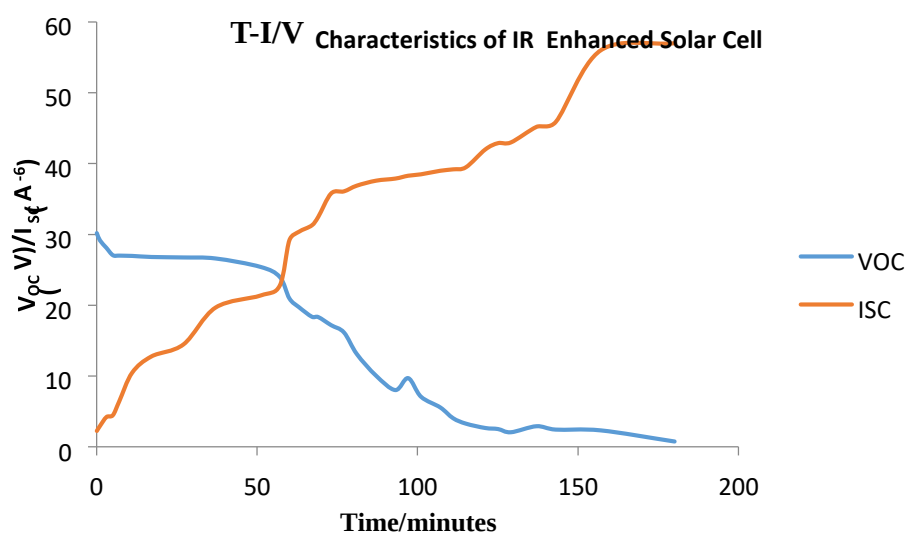


Figure 2: T-I/V Characteristics of IR Enhanced Solar Cell

Figure 2 shows variation of potential V_{OC} (V) and short circuit current (I_{SC}) (μA) with time (minutes). Potential was initially observed to built up to 30.21V, while the decay in gradually in minimum solar radiation for the three hours the cell was monitored under minimum radiation. Some residual potential were observed at 0.8V and some level of charge carriers generating a current of $57\mu A$. The residual power of $45.6\mu W$ which could sustain an LED within a duration of several minutes. Another experiment was conducted IR enhancing diode solar cell and the results were recorded in Table 2.

Table 2: T-I/V Characteristics of a Solar Cell Void of IR Enhancement Element

Time/Minutes	V_{OC} (V)	I_{SC}
0	10.16	0.29
1	10.07	0.3
3	9.48	0.5
5	9.35	0.71
7	9.22	0.8
11	9.18	1.5
17	9.11	1.8
27	9.09	2.23
37	8.52	2.35
51	8.4	2.4
57	7.18	2.6
60	6.98	2.62
63	6.62	2.74
67	5.41	2.83
69	5.12	2.95
73	4.32	3
77	4.19	3.1
81	3.4	3.39
87	3.11	3.46
93	2.76	3.69

97	2.35	3.8
101	1.6	3.98
107	1.27	4.19
111	0.6	4.2
115	0.2	4.5
121	0	4.72
125	0	4.72
129	0	4.7
137	0	4.69
143	0	4.68
157	0	4.5
180	0	4.42

From the results of Table 2, a graphical presentation of time against the current generated and potential decay were observed as shown in Figure 3.

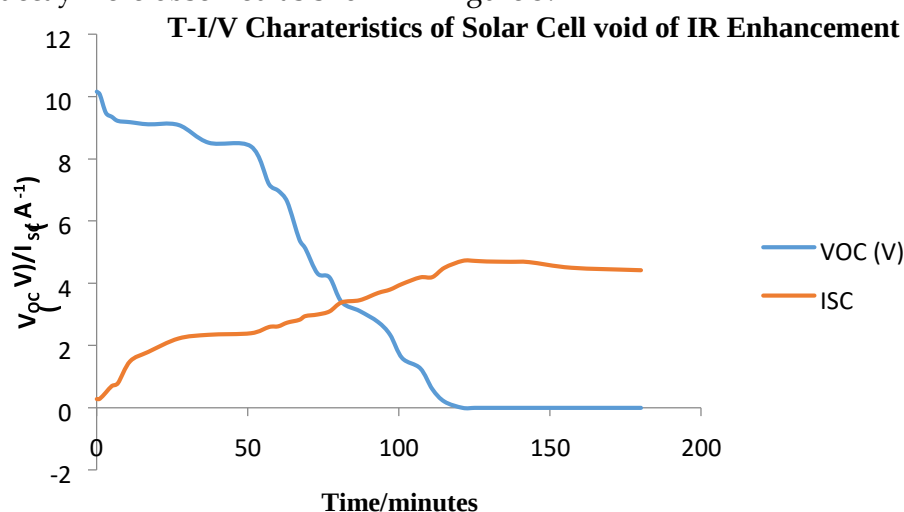


Figure 3: T-I/V characteristics of the solar cell void of IR enhancement element

The result of Figure 3 shows minimum potential (V_{oc}) of 0.2V and short circuit current (I_{sc}) of $4.42\mu A$ respectively observed within the duration of two hours power (P_{MAX}) generated was $0.38\mu W$.

Table 3: P_{MAX} (IR) and P_{MAX} (void) Characteristics of the Solar Cell.

Time/minutes	$P_{(IR)}$	$P_{(V)}$
0	69.1	2.95
1	87.5	3.02
3	119.5	4.74
5	122.2	6.64
7	175.2	7.4
11	283.4	13.8
17	343.6	16.4
27	388.2	20.3
37	524.6	20
51	544.4	20.2
57	547.7	18.7
60	612.9	18.3
63	600.4	18.2
67	576.2	15.3
69	596.7	15.1
73	616.5	12.9
77	584.5	12.9
81	485.2	11.5
87	379.4	10.8
93	305.5	10.2
97	373.04	8.9

101	274.1	6.4
107	218.8	5.3
111	160.3	2.5
115	131.1	0.9
121	113.8	0
125	109.8	0
129	90.7	0
137	133.8	0
143	113.8	0
157	132.7	0

From the results of Table 3, a characteristic plot was made of time against power generated by IR enhance solar cell to that void as shown in Figure 4.

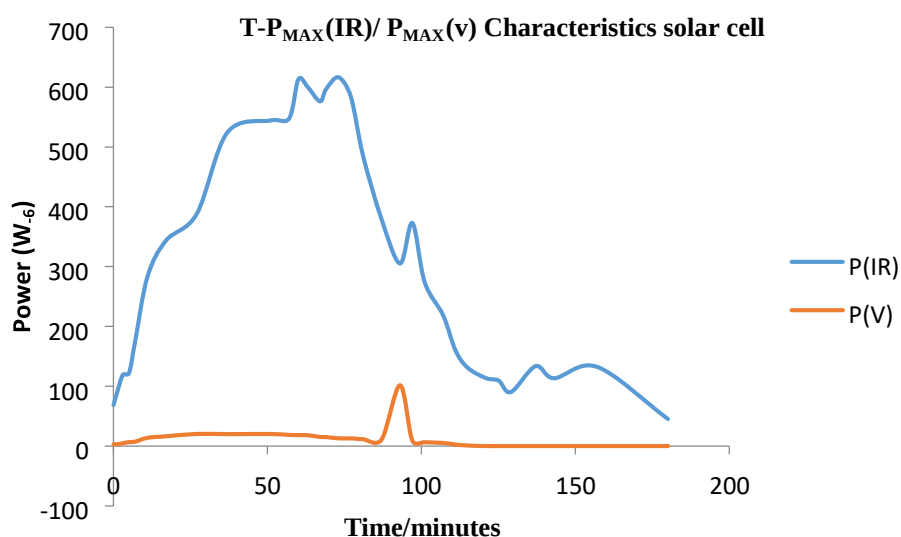


Figure 4: T-P_{MAX} (IR)/P_{MAX} (v) Characteristics Solar Cell at Minimum Solar Radiation.

The result of Figure 4 shows that the IR solar cell generated energy of ($612.9\mu W$) in minimum solar radiation and sustained to ($45.6\mu W$) up to the end of the three hours void of natural solar radiation. The IR diode enhancement contributed to gradual decay of radiation since the P_{MAX} generated by that void was recorded at a negligible value ($20.3\mu W$) which finally decayed to zero.

Discussion

The study revealed that at the IR enhanced contributed to a gradual delay in charge carrier generation which could support sensitive services in the absence of chemical stored grid energy for a longer duration. There was a wide in production between power and current from the two energy resources. At low irradiance, the IR enhanced solar cell sustained upto 0.8V with a current of $57\mu A$.

Finally, while there was a maximum difference in the sustained potential of 21.4% two hours after withdrawal of natural radiation the gap between the current generated was above 30%. The power of the cell void of IR enhancement was almost at negligible value after 111minutes.

Conclusion

Study showed that the IR diode increased the power output of the solar cell to more than 300%. An indication that it can support the life time of energy in emergency cases in regions of low solar radiation.

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