

Sensibility of electrical parameters to the illumination intensity in solar cells

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The effect of illumination intensity on the solar cell parameters has been investigated based on the one-diode model. In this study we made measurements on (i) a typical monocrystalline silicon homostructure cell (blue c-Si SAT solar cell), which is considered as a reference ideal cell (high quality), and (ii) a low quality front wall Cu₂S-CdS heterostructure. The dependence of the cell parameters on illumination intensity for the range 20 - 100 mW/cm² at $T = 300$ K has been investigated. It was found that the V_{max} voltage at the maximum power point is located in the neighbourhood of V_{oc} for the ideal silicon SAT solar cell, while for Cu₂S-CdS cell, it was in the neighbourhood of $f \times V_{oc}$, where f is the golden number conjugate. The maximum electrical output power delivered by the two cell types follows a linear variation with the illumination intensity level E . In the case of the ideal SAT solar cell, series resistance decayed exponentially when illumination intensities E increases while in the case of the Cu₂S-CdS solar cell, this behaviour was observed for the shunt resistance.

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1. Introduction

As any electronic device, the solar cell is subjected to internal and external constraints. For example, it suffers from degradation due to several environmental factors such as exposure to high temperature and illumination. Study the sensibility of electrical parameters to the illumination intensity in solar cells become crucial for the optimization of fabrication processes and other scientific research [1].

The determination of the descriptive electrical parameters at a specific illumination intensity has been investigated by several researchers [1], [2], [3], but the effect of illumination intensities on these cell parameters are rather scarce in literature [4], [5], [6].

Several authors proposed various methods for extracting these parameters that describe the non-linear electrical model of solar cells, such as, numerical method [2], [7], [8], neural network [9] and genetic algorithm [10].

The aim of the present work is to investigate the illumination intensity effect on the parameters of the solar cells by considering the one-diode equivalent circuit model given by equation 1

$$I = I_{ph} - \frac{V + R_s I}{R_{sh}} - I_s \left[\exp\left(\frac{q(V + R_s I)}{nkT}\right) - 1 \right] \quad (1)$$

Where T is the temperature, q is the electron charge, k is the Boltzmann constant, I is the output current, I_{ph} is the photocurrent, I_s is the reverse saturation current, n is the diode ideality factor of the

junction, and R_s and R_{sh} are the series and the shunt resistance, respectively.

In this study, a blue c-Si SAT [11] and a Cu₂S-CdS solar cells are used.

2. Experimental procedure

The used light source is a 100 W quartz-halogen lamp with strand of tungsten (3200 K) for simulation AM 1.5. Light is filtered by a water ground glass tank of 2 cm thick [12] to insure a uniform illumination over the whole cell area and to cut the IR emitted by the lamp.

The cell is fixed to a printed circuit. An automatically controlled system is used to command the power supply of the lamp and to maintain constant illumination intensity [13]. Temperature is measured by a 100 ohms platinum surface resistance sensor of 1 mm² and read on a digital thermometer to the tenth of degree. The circuit used to polarize the solar cell is a potentiometric type that can support currents up to 1A. With a set of optical filters-Neutral Density the intensity illumination is varied. I (V) characteristics are plotted on a X-Y recorder and displayed on a PC screen.

In this study, two types of solar cells were investigated: (a) a high quality silicon solar cell, blue type, square, of area 4 cm², supplied by SAT [11]; (b) a low quality front wall Cu₂S-CdS heterostructure solar cell, square, of area 4.28 cm², realized by wet process and having the following structure (Fig.1).

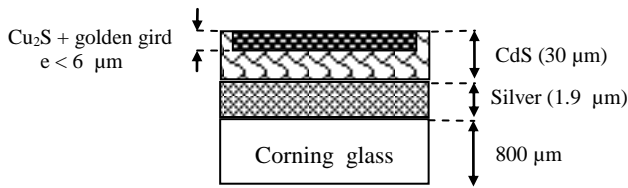


Fig. 1. Cu_2S -CdS Solar cell structure.

3. Results and discussion

3.1 $I(V)$ measurement and variation of the remarkable points values with illumination intensities

The $I(V)$ characteristics for both the blue c-Si SAT and the front wall Cu_2S -CdS solar cells under illumination of 20 to 100 mW/cm^2 at a fixed temperature (300 K) are shown in figure 2.

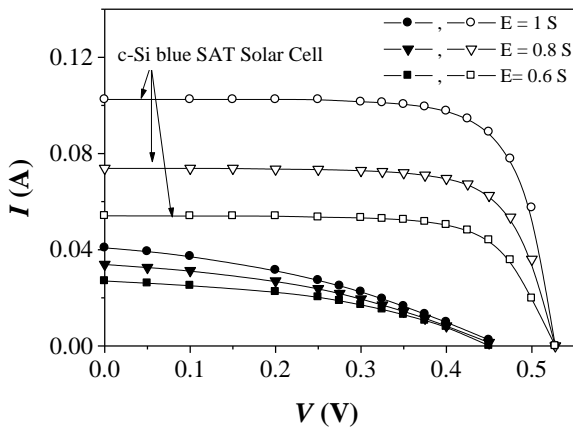


Fig. 2. $I(V)$ characteristics at $T = 300\text{ K}$ and under various illumination intensities E for both the blue c-Si SAT and the front wall Cu_2S -CdS solar cells.

The remarkable points values of the $I(V)$ characteristics are the open circuit voltage V_{oc} , the short circuit current I_{sc} and the differential resistances R_{so} and R_{sho} at the $(V_{oc}, 0)$ and $(0, I_{sc})$ points, respectively. These experimental data are listed in Table 1.

The open-circuit voltage V_{oc} depends mainly on the energy gap width of the material. Therefore, it must remain almost constant with the illumination intensity. This result is well illustrated by Fig. 2, and table 1. We observed that V_{oc} increases from 514 mV to 536 mV

for the blue c-Si SAT solar cell, and from 440 mV to 469 mV for the Cu_2S -CdS solar cell. Such increase may be attributed to the inaccuracy of the measurement.

From table 1 a linear variation of I_{sc} versus the illumination intensity is observed. In the range 20 - 100 mW/cm^2 , I_{sc} value increases from 40 to 100 mA and from 10 to 41 mA for the blue c-Si SAT and the Cu_2S -CdS solar cells respectively expressing so a better collection of photons (quantum efficiency) in the high quality solar cell. Indeed, the short-circuit current I_{sc} is determined not only by the illumination intensity of the light source but also by the spectral response (the probability of creating an electron-hole pairs per an incident photon) of the cell. The spectral response depends in its turn on the optical absorption coefficient, junction depth, width of the Space-Charge Region (SCR), life times and motilities of carriers on both sides of the junction, the presence of electric fields on both sides of the SCR, and the surface recombination velocity [14].

3.2 Variation of the descriptive electrical parameters of the one-diode equivalent circuit model with illumination intensities.

The descriptive electrical parameters of the one-diode equivalent circuit model are the photocurrent I_{ph} , the series resistance R_s , the shunt resistance R_{sh} , the reverse saturation current I_s , and the diode ideality factor n of the junction. These parameters were determined by the numerical method elaborated by J-P. Charles *et al.* [7] and listed in Table 2.

The behaviour of the series resistance R_s changes considerably from one cell to other. It depends not only on the resistivity of the material and of its thickness, but also on the possible presence of interface layer, and resistances that may develop in the contact region [15].

In table 2, the series resistance R_s remains almost constant in the Cu_2S -CdS solar cell while in the case of the high quality SAT solar cell, it decreases exponentially when illumination intensities E increases as shown in Fig 3-a. Earlier researchers [5], [16], [17] have also found R_s decreases when E increases. As pointed out by Arora *et al.* [17], the decrease can be attributed to the increase in conductivity of the active layer with the increase in the intensity of illumination.

Table 1. Experimental remarkable points values extracted from the $I(V)$ characteristics for both the blue c-Si SAT and the $\text{Cu}_2\text{S-CdS}$ solar cells at $T = 300\text{ K}$, and under various illumination intensities. E is expressed in Sun (S). $1S = 100\text{ mW/cm}^2 = \text{AM1.5}$.

Cell	E (S)	1	0.8	0.6	0.4	0.2
c-Si SAT solar cell	V_{oc} (mV)	536	527	525	512	514
	I_{sc} (mA)	100	74	65	41	40
	R_{so} (Ω)	0.45	0.59	0.69	1.19	1.18
	R_{sho} ($\text{K}\Omega$)	1	1	1	1	1
$\text{Cu}_2\text{S-CdS}$ solar cell	V_{oc} (mV)	469	461	468	450	440
	I_{sc} (mA)	41	34	27	18	10
	R_{so} (Ω)	6.86	7.03	8.15	8.98	12.1
	R_{sho} (Ω)	42	51	74	97	166

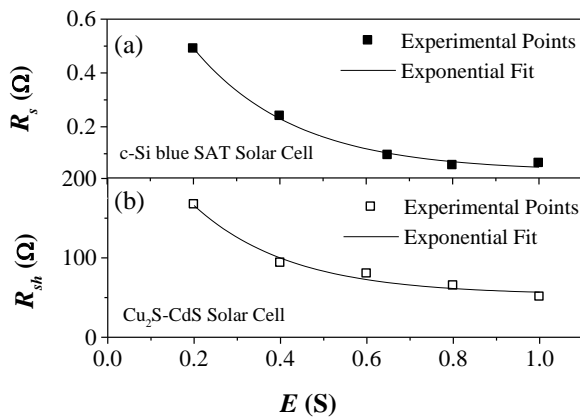


Fig. 3. Variation of the series resistance R_s of the SAT cell (a), and the shunt resistance R_{sh} of the $\text{Cu}_2\text{S-CdS}$ cell (b) versus illumination levels E at $T = 300\text{ K}$.

In the $\text{Cu}_2\text{S-CdS}$ solar cell an exponential decay of the shunt resistance R_{sh} when E increases was observed (Fig. 3-b). This decrease may be attributed to the existence of local inhomogeneities leading to non-uniform current flow or to charge leakage across the p-n junction in the cell. In the ideal SAT solar cell, the shunt resistance remains at a constant high value (Table 2), expressing so the weak existence of defects indicated above.

Table 2 shows a weak linear increase variation law of I_s versus illumination levels for the blue c-Si SAT solar cell expressing so a weak existence of an effective lifetimes of the minority carriers in the SCR. Furthermore, a random variation for the $\text{Cu}_2\text{S-CdS}$ cell was observed, expressing in more the existence of a recombination centers density and a capture cross section for electrons [18], [19].

As the photocurrent I_{ph} results from the conversion of photons to electric carriers, an increase linear variation law with illumination E for the two cells was observed. The I_{ph} values are more important in the case

of the high quality c-Si SAT solar cell, expressing so a higher conversion process (Table 2).

The value of the diode ideality factor n brings major information on the internal conduction mechanisms. Its value depends on the current transport mechanism [20]. The sensibility of n on illumination intensity E is almost non-existent in the case of the ideal cell (Fig. 4-a), n value increased from 1.5 to 1.52 expressing so the existence of diffusion and generation-recombination current mechanisms in the SCR [20]. This sensibility of n on illumination was inconsistent in the case of a low quality cell. It was fluctuating between the values 1.95 and 2.8 (see Fig 4-b). This behaviour implies that the transport mechanism for this device would be a combination of several regimes such as generation-recombination current mechanisms in the SCR, and tunnelling conduction effect [20].

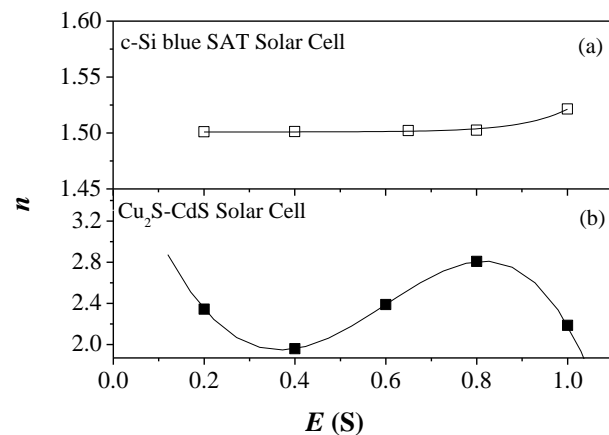


Fig. 4. Variation of the diode ideality factor n versus illumination levels E at $T = 300\text{ K}$ for both the blue c-Si SAT and the $\text{Cu}_2\text{S-CdS}$ solar cells.

3.3 Variation of the maximum electrical output power with illumination intensities.

In Fig. 5, results show that the V_{max} voltage at the maximum output power point is independent of the illumination intensities for the two cell types. Etienne Saloux *et al.* [21] have observed a similar independence of V_{max} of illumination intensity. They have also found that the temperature affects mainly the voltage while the current seems to be mostly affected by the illumination intensities. For the silicon SAT solar cell, V_{max} value is close to V_{oc} , while for $\text{Cu}_2\text{S-CdS}$ cell, it is close to $f \times V_{oc}$, where f is the golden number conjugate ($f = (\sqrt{5} - 1) / 2 \approx 0.618$). Many authors make claims that this mathematical entity is ubiquitous in nature, art, architecture, and anatomy [22], [23].

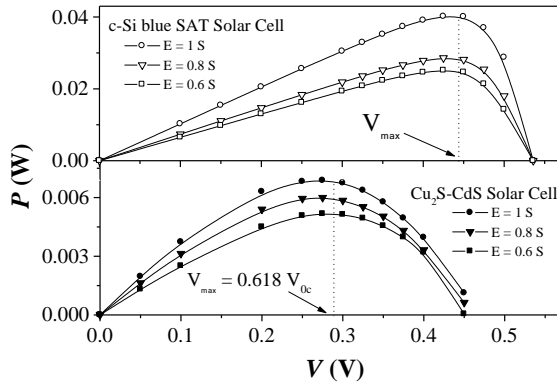


Fig. 5. Electrical output power versus bias voltage curves of the blue c-Si SAT (top) and the $\text{Cu}_2\text{S-CdS}$ (bottom) solar cells at $T = 300 \text{ K}$ and under various illumination intensities E .

The maximum electrical output power P_{max} delivered by the two cell types varies linearly with the illumination intensity E (Fig. 6). Its value increases from $0.7 \times 10^{-2} \text{ W}$ to $4.04 \times 10^{-2} \text{ W}$ for the blue c-Si SAT cell and from $0.22 \times 10^{-2} \text{ W}$ to $0.69 \times 10^{-2} \text{ W}$ for the $\text{Cu}_2\text{S-CdS}$ cell, showing so a fastest rate of change in the case of the high quality blue c-Si SAT cell.

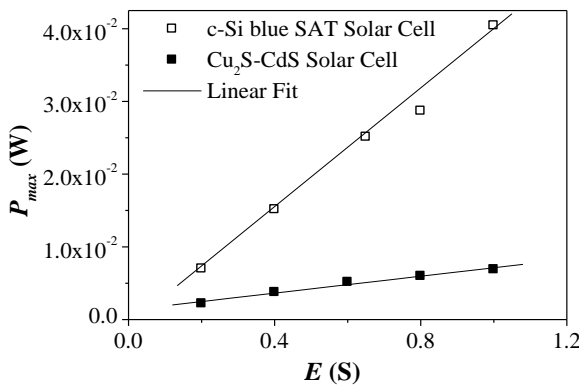


Fig. 6 Maximum output power as a function of illumination intensities for both the blue c-Si SAT and the $\text{Cu}_2\text{S-CdS}$ solar cells at $T = 300 \text{ K}$.

3.4 Variation of the optimal resistance load with illumination intensities.

The optimal resistance load is given by equation 2

$$V_{max} = R_{op} I_{max} \quad (2)$$

This resistance R_{op} is connected at the end of the cell to have the maximum output power.

As V_{max} was almost constant and P_{max} increases linearly with E , the current I_{max} increases also linearly with the illumination intensity E . Thus, R_{op} decreases with increasing E for both cells. Results in Table 3 illustrate this effect.

From Table 3, the optimal resistance value decreases by 59 % (from 11.5Ω at $E = 20 \text{ mW/cm}^2$ to 4.7Ω at $E = 100 \text{ mW/cm}^2$) for the blue c-Si SAT solar cell, and decreases by 74 % (from 40.1Ω at $E = 20 \text{ mW/cm}^2$ to 10.25Ω at $E = 100 \text{ mW/cm}^2$) for the $\text{Cu}_2\text{S-CdS}$ solar cell, expressing so a better stability of the optimal resistance load value in the case of the high quality solar cell.

4. Conclusion

In this study we examined the sensibility of electrical descriptive parameters to the illumination intensity for high and low quality solar cells in the range $20 - 100 \text{ mW/cm}^2$ and at $T = 300 \text{ K}$.

We found that the series resistance R_s followed an exponential decay with increasing E in the case of the SAT solar cell. This behavior was observed for the shunt resistance R_{sh} in the case of the low quality $\text{Cu}_2\text{S-CdS}$ solar cell. It was found that the V_{max} voltage at the maximum power point was close to the value of V_{oc} in the case of the SAT solar cell, while for the $\text{Cu}_2\text{S-CdS}$ cell, it was close to the value $f \times V_{oc}$, where f is the golden number conjugate. It was found also that the sensibility to the illumination intensity of the diode ideality factor n and the reverse saturation current I_s is almost non-existent in the case of the ideal cell and inconsistent in the case of the real cell. A better stability of the optimal resistance load value in the case of the high quality solar cell was found.

Table 2. Calculated values of the descriptive electrical parameters using the one-diode model for both the blue c-Si SAT and the Cu₂S-CdS solar cells at $T = 300$ K and under various illumination intensities E .

Cell	E (S)	1	0.8	0.6	0.4	0.2
c-Si SAT solar cell	I_{ph} (mA)	102	74	65	54	41
	I_s (A) $\times 10^{-8}$	9.48	8.96	8.50	8.09	7.56
	R_s (m Ω)	64.7	56.5	94.1	239	490
	R_{sh} (K Ω)	1	1	1	1	1.02
	n	1.52	1.50	1.50	1.50	1.50
Cu ₂ S-CdS solar cell	I_{ph} (mA)	47	38	29	19	11
	I_s (A) $\times 10^{-8}$	3.69	4.87	6.49	1.72	4.45
	R_s (m Ω)	5.43	4.87	5.69	5.71	5.18
	R_{sh} (K Ω)	50.84	64.89	80.04	93.52	167.2
	n	2.18	2.80	2.38	1.95	2.34

Table 3. Measured values of the optimal resistance load R_{op} for both the blue c-Si SAT and the Cu₂S-CdS solar cells at $T = 300$ K and under various illumination intensities E .

Cell	E (S)	1	0.8	0.6	0.4	0.2
c-Si SAT solar cell	R_{op} (Ω)	4.7	6.65	7.20	8.80	11.5
Cu ₂ S-CdS solar cell	R_{op} (Ω)	10.25	12.2	14.8	22.8	40.1

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