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Effect of Temperature on Electrical Parameters of Phosphorous Spin–on Diffusion of Polysilicon Solar Cells

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ABSTRACT

Effects of temperature on electrical parameters of polysilicon solar cells, fabricated using the phosphorous spin-on diffusion technique, have been studied. The current density–voltage characteristics of polycrystalline silicon solar cells were measured in dark at different temperature levels. For this purpose, a diode equivalent model was used to obtain saturation current densities measured at the required temperatures. The experimental results showed that the increase in temperature from 27 to 70˚C produced a rapid increase in the saturation current densities from 0.00003 to 0.0005A. The changes in the open circuit voltage and the short circuit current density were found to be linear with the temperature variations: about 3 mV/˚C reduction in the open circuit voltage was observed. Measurements of the short circuit current density revealed a very small dependency of the current density on the temperature variations. Accordingly, the short circuit current density increased from 17.8 to 18.4 mA with increase in temperature from 27 to 107˚C. Measurements of the output power versus load resistance were obtained at different temperature levels. The results showed that the output power dropped by 30% with temperature rise from 27 to 107˚C.

1. INTRODUCTION

Effects of temperature on the output characteristics of the solar cells have been studied by many researchers [1-5]. However, the results of these early investigations and those of the later authors [6-15] have not always been consistent with each other. For example, temperature dependency of full-spectrum photovoltaic parameters for polycrystalline PV module was studied experimentally as given in Ref. [15]. In this study, the measurements were performed under outdoor environment conditions. This study shows that unlike the situation for conventional PV devices, these cells actually exhibit decrease in efficiency with increasing temperature (reaching a value of 0.05 % at 60°C).

Solar cells, whether used for space applications or for power generation on earth, experience different working temperatures throughout their life cycle. It is therefore, important to understand the behavior of the cells at different temperatures. Moreover, the cells, being semiconductor elements, are sensitive to temperature. Any substantial increase in temperature reduces the band gap of the semiconductor material, from which solar cells are made. This affects most of the parameters of the semiconductor. The decrease in the band gap of a semiconductor due to increase in temperature may be considered as the cause for increasing the energy of the electrons in the material. Therefore, the aforementioned reason makes it necessary to study the effects of change in working temperatures of solar cells on their electrical characteristics.

In general, as temperature rises, open circuit voltage decreases rapidly and short circuit current density increases slowly. However, the observed rates of increase of current density with increase in temperature reported by different authors differ widely.

In the this experimental investigation, our results pertaining to the study of the effects of temperature on some important electrical parameters, such as saturation current density, open circuit voltage, short circuit current density, and the output power of polysilicon solar cells with N+ / P structures, fabricated using spin-on diffusion technique, have been presented. The advantages of spin-on diffusion technique for fabrication of solar cells are presented in Ref. [16]. The current density–voltage characteristics of polycrystalline silicon solar cells were measured in dark at different temperature levels. In order to obtain saturation current densities measured at these temperatures, a diode equivalent model has been used.

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2. THEORETICAL BACKGROUND

The silicon p-n junction solar cell is sensitive to temperature change. This is due to the fact that the band gap of the silicon solar cell is reduced by increasing its temperature. Therefore, decrease in the band gap with rise in temperature can increase the energy of the electrons in the p-n junction.

In a solar cell, the reverse saturation current density, I_0, is the parameter that is the most significantly affected by increase in temperature. The reverse saturation current density from one side of a p-n junction is given as:

$$I_0 = qA\,(Dn_i^2/LN_D) \quad (1)$$

where:

q	=	The electronic charge
D	=	The minority carrier diffusivity
L	=	The minority carrier diffusion length
N_D	=	The donor doping concentration
n_i	=	The intrinsic carrier concentration

In Equation (1), some of the parameters are temperature dependent; however, the most affected parameter is the intrinsic carrier concentration, n_i. This parameter depends on the band gap energy, which decreases with the rise in temperature, resulting in higher intrinsic carrier concentrations as given by Equation (2):

$$n_i^2 = BT^3 \exp(-Eg/kT) \quad (2)$$

where:

T	=	Temperature
Eg	=	Band gap
B	=	A constant coefficient, which is essentially independent of temperature
k	=	Boltzmann constant

If temperature dependencies of the other parameters are neglected, then the substitution of Equation (2) in Equation (1) gives:

$$I_0 = (qAD/LN_D)BT^3\exp(-Eg/kT) \quad (3)$$

The temperature dependency of the reverse saturation current density, I_0, can be clearly observed from Equation (3).

The impact of I_0 on the open circuit voltage, V_{oc}, can be estimated by substituting Equation (3) in the equation for V_{oc} as shown in Equation (4):

$$V_{oc}=(kT/q)\,Ln(I_{sc}/I_0)$$
$$V_{oc}=(kT/q)\,[Ln(I_{sc})-Ln(I_0)] \quad (4)$$
$$V_{oc}=(kT/q)\,[Ln(I_{sc}-Ln(B^*T^3\exp(-Eg/k))]$$
$$V_{oc}=(kT/q)\,(Ln(I_{sc})–Ln(B^*)–3Ln(T)+(Eg/kT))$$

where, V_{oc} and I_{sc} are the open circuit voltage and the short circuit current density, respectively, B^* is a temperature independent constant, and $E_g = qV_g$. Assuming that the term dV_{oc}/dT does not depend on dI_{sc}/dT, then it can be determined as given by Equation (5):

$$dV_{oc}/dT = ((V_{oc}-Vg)/T) – 3(k/q) \quad (5)$$

The above equation shows that the temperature sensitivity of a solar cell depends on the open circuit voltage of the solar cell.

3. EXPERIMENTAL METHOD

In order to perform the experiments, it was necessary to fabricate the required solar cells. As the first step in the fabrication of solar cells, it is necessary to form a p-n junction. The starting material selected was p-type silicon of 2 in. diameter, doped with boron to 1022 m^{-3}. The p-n junction formation was carried out using phosphorous spin–on diffusion technique. The advantages of spin-on diffusion technique for fabrication of solar cells are presented in Ref. [16].

The variation in temperature of the solar cells was achieved using the heating effect from a heater of size 6 × 6 cm^2. A thermocouple was attached to the copper plate and the experimental cell was fixed onto the plate heater, which was controlled by a PID controller. It was assumed that due to high thermal conductivity, temperature of the copper plate almost equals that of the solar cell. Therefore, in the actual experiment, the measured temperature was that of the copper plate and not of the cell. Additionally, an experiment was carried out to determine the temperature difference, if any, between the cell and the copper plate. For this purpose, a second thermocouple was attached on top of the cell, and the readings of the two thermocouples were compared. The measured difference in the two readings was less than 1˚C at temperatures below 50˚C and between 1 and 2 ˚C for temperatures up to 100 ˚C.

4. RESULTS AND DISCUSSION

Variations of the measurements for I–V characteristic curves (diode characteristic curves) of polysilicon solar cells, fabricated in laboratory by the authors, for un-illuminated condition at two different temperature levels are shown in Fig. 1. These variations are due to the temperature dependency of the cell parameters.

The diode forward characteristic curve allows for the determination of I_0. Here, the cell is not illuminated and a variable voltage is applied to terminals such that the p-n junction is forward biased .Then, on application of equation, $I = I_0 \exp(qV/kT)$, a plot of $Ln(I)$ vs. V will result in a straight line. Subsequently, from the intercept of the line, the reverse saturation current density can be calculated. The results show that for a temperature rise from 27 to 70˚C, the reverse saturation current density increases from 0.00003 to 0.0005A.

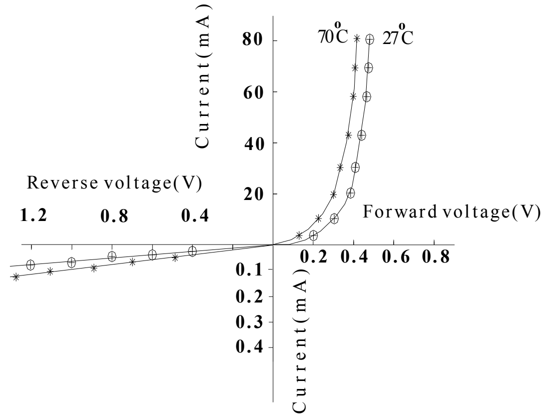

Figure 1. I-V characteristic curves for the un-illuminated polysilicon solar cells at two temperatures

As shown in Fig. 2, the open circuit voltage decreases with increase in temperature, which is mainly due to the temperature dependency of the reverse saturation current density, which is evident from Equation (4). The drop in V_{oc} is found to be about 129 *mV* for temperature change from 27 to 70˚C.

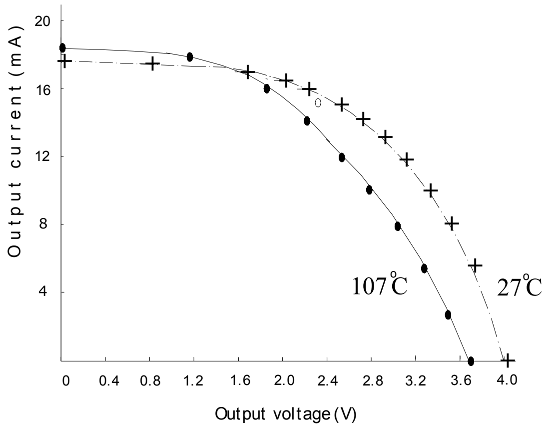

Figure 2. I-V characteristic curves of the fabricated polysilicon solar cell at different temperatures

Fig. 3 shows the variations in the open circuit voltage with temperature change. These variations are found to be linear with temperature: in this case, about 3 *mV/˚C* reduction in the open circuit voltage can be observed with the temperature rise.

The short circuit current density, I_{sc}, increases slightly with temperature. This is because the band gap energy, E_g, decreases, and a larger number of photons have enough energy to create *e-h* pairs. However, this is a small effect, and the temperature dependency of silicon solar cell short circuit current density is very small, which can be observed from the curves of the temperature effect on the *I–V* characteristic of the fabricated polysilicon solar cells. An increase of about 0.6 *mA* in the short circuit current density for 27 to 107˚C temperature increase can be observed in Fig. 4. The changes in I_{sc} are found to be linear with temperature as shown in this figure.

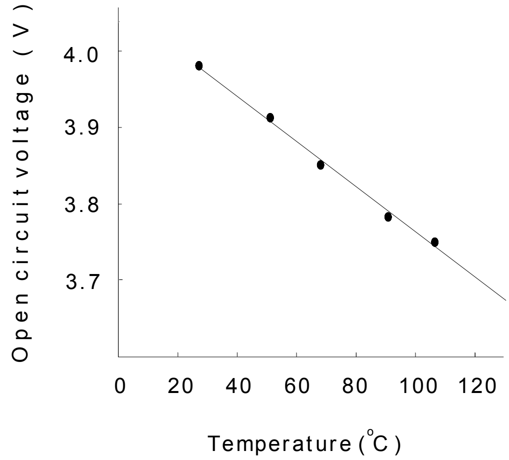

Figure 3. Variations of the open circuit voltage at different temperatures

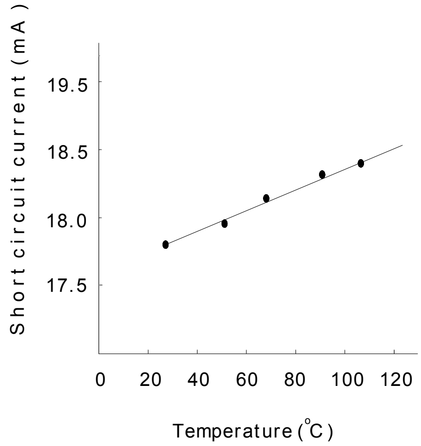

Figure 4. The short circuit current density variations at different temperatures

The generated power by the solar cells is determined by exposing the cells to sunlight and measuring the voltage produced across a decade resistance box. The current densities generated for various load resistances are obtained from the application of the Ohm s' law.

Electrical power output of the fabricated polysilicon solar cells, as a function of external load resistance, is depicted in Fig. 5 at various temperature levels. As shown, an output power drop from 39.6 to 27.7 *mW* occurs due to a temperature increase of about 80 ˚C. These variations are due to the temperature dependency of the cell parameters, which were discussed earlier. The different output powers observed at different temperatures are due to the dependency of output current density on temperature.

The diode current density varies with temperature at rates higher than the generated current, I_L. As shown in Fig. 5, I_L is substantially independent of temperature; therefore, the temperature increase of about 80˚C causes a drop of 30% in the output power. This is mainly because I_L is not a rapidly varying function of temperature for heavily doped materials. As the result, its temperature dependency will be neglected.

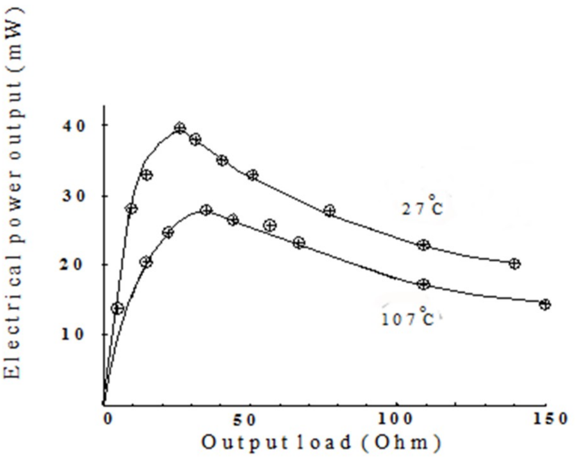

Figure 5. Electrical power output versus output load at different temperatures

5. CONCLUSIONS

The experimental results show that the parameter that is most affected by increase in temperature is the reverse saturation current density, I_0, which changes from 0.00003 to 0.0005A for a temperature increase from 27 to 70˚C.

The experimental observations pertaining to the effect of I_0 on open circuit voltage were consistent with the relevant theory. Accordingly, the open circuit voltage of the fabricated polysilicon solar cells showed drops ranging from 3.98 to 3.851 volts for temperature increase from 27 to 70˚C. The change in V_{oc} was found to be linear with temperature; about 3 $mV/˚C$ reduction in the open circuit voltage was observed with the rise in temperature.

The experimental results of the short circuit current density revealed that the current temperature dependence of the fabricated solar cells was very small. The short circuit current density increased from 17.8 to 18.4 mA on increasing the temperature from 27 to 107 ˚C. The change in I_{sc} was also found to be linear with the temperature variations.

Measurements of the output power versus load resistance for the fabricated solar cells also showed that the output power dropped 30% on temperature increase from 27 to 107 ˚C. The rapid fall in the output power is mainly due to the greater temperature dependency of the diode current compared to the incident radiation generated current. This rapid reduction of the output power suggests that in order to maintain an appropriate solar cells efficiency, the temperature of the cells must be controlled within acceptable margins.

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NOMENCALTURE

B	Constant coefficient used in Equation (2)
$\mathbf{B^*}$	Temperature independent constant used in Equation (4)
D	Minority carrier diffusivity
Eg	Band gap
$\mathbf{I_0}$	Reverse saturation current density
$\mathbf{I_{sc}}$	Short circuit current density
k	Boltzmann constant
L	Minority carrier diffusion length
$\mathbf{N_D}$	Donor doping concentration
$\mathbf{n_i}$	Intrinsic carrier concentration
q	Electronic charge
T	Temperature
$\mathbf{V_{oc}}$	Open circuit voltage

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