Temperature Effect on Intermediate Band Solar Cells (IBSCs)

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Abstract: Temperature has profound effect on the performance of solar cells. Most of the electrical processes in the semiconductor devices depend on the temperature and revealed in dramatically variations in their characteristics such as open circuit voltage, short circuit current, power conversion efficiency and the band gap of semiconductor. The aim of this paper is investigation of temperature effects on the Intermediate Band Solar Cells (IBSCs). The theoretical results indicate that performance of this type of the solar cells is low at high temperatures. Increasing in temperature from 300K to 600K decreases the efficiency of solar cell from 63% to 59 % and this decrement continues with temperature increment. This is while temperature can decrease the open circuit voltage and increase the short circuit current.

1 INTRODUCTION

Photovoltaic phenomenon is the most interesting field that converts the solar radiation to the electrical energy. In order to studying this filed of science some parameters should be considered and influence of the power conversion efficiency such as temperature effect is one of the important parameters. Generally, solar cells operate under terrestrial temperature conditions below than 350K (Sze and Ng, 1981) and in the temperatures higher than room temperature, we obvious different behaviours. For increasing the intensity of solar irradiance the concentrators and mirrors on the solar cell have been used that increases the power conversion efficiency. However, these methods have negative effects on solar cell. For example they have thermalization effects on the cell.

Thermalization of cell can be created by photons with energy higher than the band gap (Takeda and Motohiro ,2013 , Singh, Lal and Husain, 2008) and it can effect on the performance of solar cells and optoelectronic characteristics such as carrier mobility and the optical band gap (Landis, Raffaelle, and Merritt, 2004). For overcoming this effect the materials with broad band gap can operate as best candidates. The Silicon Carbide (SiC) can be used for this aim due to its wider band gap, which harvests high energy photons. Another advantage of SiC is the high stability of the material (Rostami, Heidarzadeh, Baghban, Dolatyari, and Rasooli, 2013).

In a single junction solar cell the limiting efficiency calculated by detailed balance model is 40.7% which is achievable by a material with the band gap of 1.12 eV (Shockley and Queisser, 1961). With existing an Intermediate band between the valance band and conduction band (Luque and Marti, 1997), the limiting efficiency obtains as 63.2% for a host material with the band gap of 1.95 eV (Henry, 1980). However, in the higher temperatures these values change. The important parameters that can be defined for a solar cell are the open circuit voltage, short circuit current and efficiency and their temperature dependency can be studied. This paper investigates the temperature dependency of intermediate band solar cells based on 3C-SiC.

2 THEORETICAL BASIS

Effect of temperature on the band gap has been studied by Varshni model (Varshni, 1967, Sarswat and Free, 2012).

$$\varepsilon_{CV}(T) = \varepsilon_{CV}(0) - \frac{\alpha T^2}{T + \beta} \quad (1)$$

Where $\varepsilon_{cv}(T)$ is the band gap of semiconductor at temperature T, $\varepsilon_{cv}(0)$ is the band gap at 0K and α, β are constants and their values for 3C-SiC are 6×10^{-4} eVK^{-1} and 1200K respectively (Levinshtein, Rumyantsev and Shur , 2001).

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For analysing the cell, the detailed balance model has been used. In calculation, we use blackbody modelling of the sun. Therefore, the photon and emitted energy flux density respectively is derived from Planck's law over the energy range ε_l and ε_h (Shockley and Queisser, 1961).

$$N(\varepsilon_l,\varepsilon_h,\mu,T) = \frac{2\pi}{h^3c^2}\int_{\varepsilon_l}^{\varepsilon_h} \frac{\varepsilon^2 d\varepsilon}{\exp((\varepsilon-\mu)/KT)-1} \tag{2}$$

where μ is the chemical potential, h is the Plank constant, K is the Boltzmann constant, c is the speed of light and ε_l and ε_h are lowest and highest energy, respectively. The schematic diagram for an IBSC is shown in Figure 1.

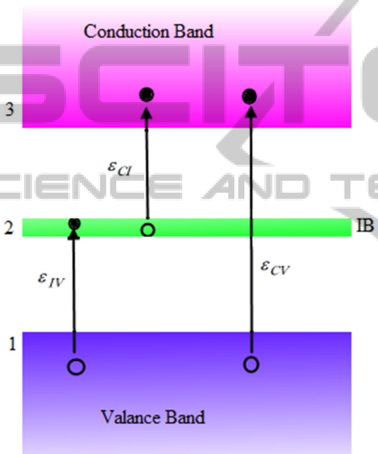

Figure 1: Schematic band diagram of an IBSC.

To develop the limiting efficiency of the IBSC we use detailed balance model and try to model the output current that extracted from contacts as:

$$\begin{aligned} J_{out} &= q\Big\{f_S.N\left(\varepsilon_l,\varepsilon_h,0,T_S\right)-f_S.N\left(\varepsilon_l,\varepsilon_h,0,T_C\right) \\ &+f_C.N\left(\varepsilon_l,\varepsilon_h,0,T_C\right)-f_C.N\left(\varepsilon_l,\varepsilon_h,\mu,T_C\right)\Big\} \\ &= q\Big\{f_S.N\left(\varepsilon_l,\varepsilon_h,0,T_S\right) \\ &+\left(f_C-f_S\right).N\left(\varepsilon_l,\varepsilon_h,0,T_C\right) \\ &-f_C.N\left(\varepsilon_l,\varepsilon_h,\mu,T_C\right)\Big\} \end{aligned} \tag{3}$$

Where q is the charge of electron, f_c and f_s is geometrical factors that depends on the angle of the cell that subtended by the sun (Mruczkiewicz, Kłos, and Krawczyk, 2008, Shockley and Queisser, 1961).

In one sun concentration, values of f_c and f_s are 2.18×10^{-5} and in maximum concentration that implies for 46050 suns their values is 1. (Quan, Zhi-Hua, Chun-Lai, Yu-Hua and Qi-Min, 2011, Green, 2001). Now with considering maximum concentration and applying to the last equation, we have the output current density as:

$$\begin{aligned} J_{out} &= q\Big\{N\left(\varepsilon_{CI},\varepsilon_{CV},0,T_S\right)-N\left(\varepsilon_{CI},\varepsilon_{CV},\mu_{CI},T_C\right) \\ &+N\left(\varepsilon_{CV},\infty,0,T_S\right)-N\left(\varepsilon_{CV},\infty,\mu_{CV},T_C\right)\Big\} \end{aligned} \tag{4}$$

Where μ_{CI}, μ_{IV} and μ_{CV} are the difference between quasi Fermi levels and we have:

$$\mu_{CV} = qV \tag{5}$$

V is the output voltage that takes account from Carnot factor (Green, 2001):

$$V_{out} = \frac{\varepsilon_{CV}}{q}\left(1-\frac{T_C}{T_S}\right) \tag{6}$$

Where T_c and T_s is the cell and the sun temperature that equals to 300K and 6000K respectively and in final the efficiency can be calculated from this:

$$\eta = \frac{V_{out}.J_{out}}{f_S\sigma T_S^4} \tag{7}$$

Where σ is the Stephan-Boltzmann constant and equals to $5.67\times10^{-8}\ W.m^{-2}.K^{-4}$ (Quinn and Martin, 1985, Blevin and Brown, 1971).

3 SIMULATION RESULTS AND DISCUSSION

In this work, we evaluate the IBSC based on SiC at different temperatures. At first we simulate the current-voltage characteristics in temperature of 300K and 600K and the results are shown in Figure 2 .

As shown in Figure 2, in the temperature of 600K, voltage and current are changed. In this temperature the band gap decreases and consequentially the voltage due to its dependency on the band gap decreases, while the current increases. However, an important point that can be revealed is the output power that these decrement and increment can change it. In this way increasing in temperature results decreasing in efficiency.

Figure 3 shows this phenomenon that in temperature 300 K, the efficiency is about 63% and in temperature 1500K it drops to 33%.

The position of IB is an important case to achieving the optimal and maximum efficiency in an IBSC. Efficiency variations versus sub band gaps have been shown in Figure 4 in 300K.

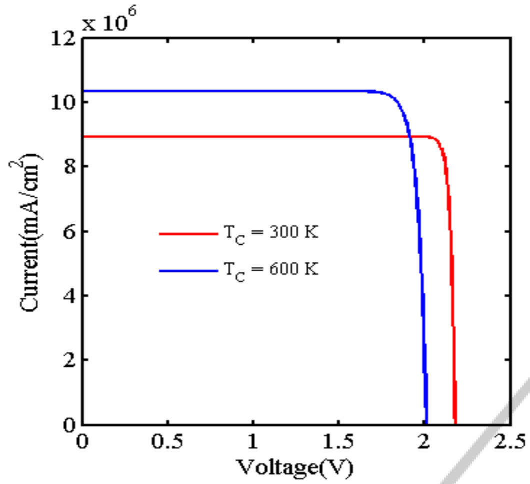

Figure 2: I-V characteristics of an IBSC in two different temperatures; 300K and 600 K.

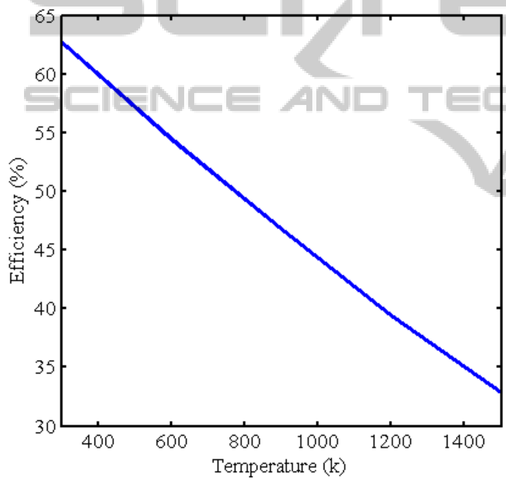

Figure 3: Efficiency versus temperature variation.

As seen in this figure, for the darker region contains from 0.6 eV to 0.8 eV for E_{iv} and from 1 eV to 1.5 eV for E_{ci}, the maximum efficiency is about 63%. In this case we have larger region for choosing the IB position. Here the introduced material is the 3C-SiC with band gap of 2.2 eV and location of this band gap is traced with dashed line. Using these information we can choose the best sub band gaps (E_{iv} and E_{ci}) to have the maximum efficiency. In this case when, the value of E_{iv} and E_{ci} is about 0.84 eV and 1.36 eV, we achieve the maximum efficiency that is about 60%.

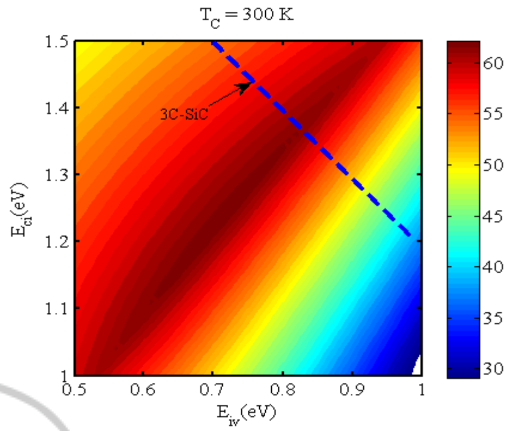

Figure 4: The influence of the position of IB on the efficiency in the temperature of 300K and location of the 3C-SiC band gap in dashed line.

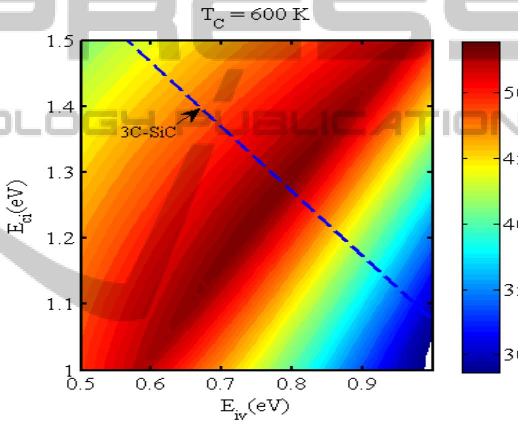

Figure 5: The influence of the position of IB on the efficiency in the temperature of 600k location of the 3C-SiC band gap in dashed line.

If the temperature increases, the total band gap changes. So the sub band gaps and position of IB change too.In the temperature of 600K (that has been shown in

Figure 5) the values of E_{iv} and E_{ci} has been changed and the maximum efficiency is about 59% that occur in the ranges between 0.65 eV to 0.85 eV for E_{iv} and between 1.1 eV to 1.35 eV for E_{ci}. In this case the ranges of E_{iv} and E_{ci} become smaller compared to Figure 4 and the band gap of 3C-SiC is reduced and is equals to 2.08 eV (dashed line shows the location and value of it). If we choose the IB position at 0.8 eV upper than the valance and 1.28eV lower than the conduction band the efficiency is maximized which is equals to 54 %.

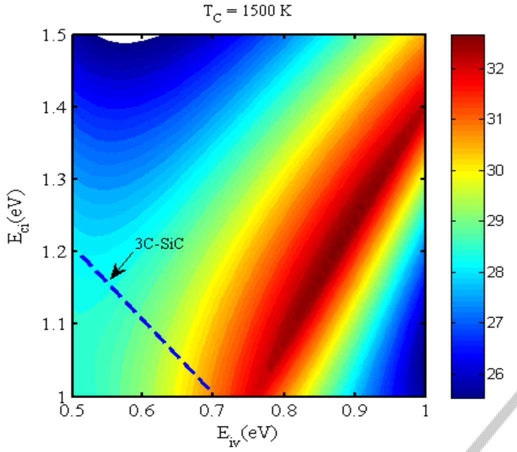

Figure 6: The influence of the position of IB on the efficiency in the temperature of 1500K.

In the temperatures of 1500K that is shown in the Figure 6, the maximum efficiency decreases to about 33% and the location of the IB has been changed. The darker region is limited in this condition and it means that we have a limit to choosing the best IB position. Another occurred event is reducing of the band gap of 3C-SiC and its value is 1.7 eV (the dashed line). The best position of IB for achieving the maximum efficiency is 0.7 eV upper than the valance band or 1 eV lower than the conduction band.

Efficiency variation with temperature for the sub band gaps, E_{iv} and E_{ci}, are shown in the Figure 7. The efficiency decreases with increasing the temperature. So at 300K, we have the maximum efficiency that has been occurred in the 0.71 eV for E_{iv} and 1.24 eV for E_{ci} while in 900K it's drops to 55% and the value of E_{iv} and E_{ci} is about 0.6 eV and 1.2 eV respectively. These are due to the variations in the output current and voltage that results in the variation of the output power. If the temperature increases the band gap of semiconductor decreases and the voltage decreases due to its dependency to band gap but the current has increases and finally the voltage decrement plays an effective role in the efficiency decrement.

4 CONCLUSIONS

In this paper, we evaluate the IBSCs based on 3C-SiC. Our simulation shows that the open circuit voltage, short circuit current and efficiency vary with temperature increment. So in the temperature 300K the efficiency is about 63% and for example in the temperature 600K the efficiency drops to 59% and this decrement continues with temperature increment. In this regard, the open circuit voltage decreases and short circuit current increases and results in changing of the output power.

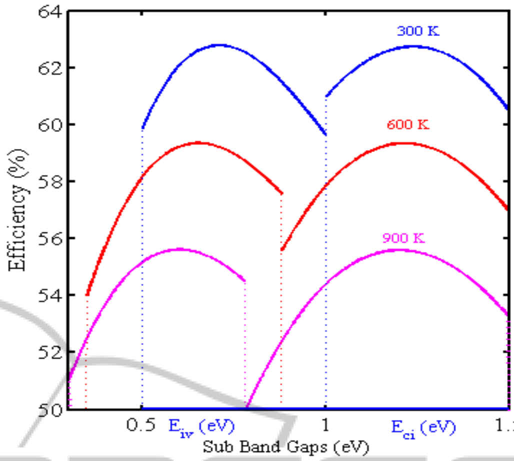

Figure 7: Efficiency versus sub band gaps (E_{iv} and E_{ci})in three different temperatures (blue curve in 300K, red curve in 600K and cyan curve in 900K).

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