Modeling the Thermal Response of $Al_{0.3}Ga_{0.7}As$/GaAs/Ge Multijunction Solar Cells

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Abstract. The III-V group of semiconductor materials are well-known for their excellent performance as high efficient solar cells. This type of material is usually arranged in a multijunction structure which allows a continuous absorption of sun's radiation. The electronic transport properties of semiconductor materials are influenced by the temperature. In this paper, the effect of temperature to the performance of $Al_{0.3}Ga_{0.7}As$/GaAs/Ge multijunction solar cells was evaluated using a simulation approach. By varying the temperature of materials to 25 ºC, 50 ºC, 75 ºC and 100 ºC in PC1D solar cell simulation, we were able to determine the performance of each cell and the overall efficiency of $Al_{0.3}Ga_{0.7}As$/GaAs/Ge multijunction solar cells. The results have shown that the increasing temperature of the materials will reduce the V_{oc} of each cell by -1.40 mV/ºC, -1.40 mV/ºC and -1.30 mV/ºC respectivelly, while the total efficiency of multijunction solar cells was reduced by -0.106%/ºC.

1. Introduction

Solar energy is one of the most abundant source of clean energy in the world. One way to harvest this type of energy and convert it into electricity is by using a solar panel which consist of solar cells. Various types of solar cells and many different techniques had been invented as a result of intensive researchs all around the world for the last five decades. The most widely used solar cells so far are made from silicon based materials which is capable to gain an efficiency up to 25% [1]. Eventhough the efficiency of silicon based solar cells is quite low as compared to other types, but the abundant source of silicon in the world and the well-mastered fabrication's techniques has made the silicon based solar cells as the most available solar cells nowadays.

The III-V based solar cells like GaInP, AlGaAs, InP, and GaAs had been known to produce a higher efficiency of above 25% [2,3,4]. The combination of those semiconductor materials in the form of multijunction solar cells, recently hold the world record of efficiency of 44.7% [5]. In a multijunction solar cells, several p-n junction of semiconducting layers (subcells) were arranged from the top to the bottom following the order of their bandgap energies. The first layer has the highest bandgap energy which is purposed to absorb the solar radiation in the small wavelength region, while the next layers with smaller bandgap energies were set to absorb solar radiation in the longer wavelength regions [6]. Theoretically, a higher rate of solar cells's efficiency would be obtained by putting more junctions in the solar cells as more junctions would increase the amount of radiation absorbed and reduce the radiation loss [7].

One of the important factor that affecting the performance and the efficiency rate of semiconductor solar cells is the temperature. The increasing ambient temperature will reduce the performance of the solar cells [8-11].The thermal response of multijunction solar cells have been studied by some researchers [12,13]. This paper is mainly focused on the effect of temperature to the performance and efficiency of $Al_{0.3}Ga_{0.7}As/GaAs/Ge$ multijunction solar cells through a simulation approach. The simulation approach in this paper is limited by some assumptions, i.e: (a) for each subcell, an independent simulation were done in order to optimize the electricity power produced by each subcell, (b) the current flows in each subcell were not identical, (c) the boundary between two adjacent cells (tunnel junction) was not taken into account and assumed to play no role in this simulation.

2. Methods

There are two steps of simulation performed in this research as illustrated in Figure 1. The first step is simulating the incoming solar radiation arrives at each subcell. The amount of radiation intensity (in Watt.m^{-2}) received by the first subcell (I_0) is AM1.5G solar radiation (ASTM G-173), while the amount of radiation received by the next subcell depends on the amount of transmitted radiation from the previous subcell following this equation :

$$I_n = I_{n-1}e^{-\alpha_n(x_n)} \tag{1}$$

where n=1,2,3.. denotes the subcell index which depend on the number of subcell used in a multijunction solar cells, while α_n and x_n denote the absorption coefficient and the thickness of each subcell.

The second step is the current producing simulation using PC1D program [15], in which all parameters affecting the electrical output of solar cells including the temperature was set. Some of the relevant outputs from this simulation are the open circuit voltage V_{oc}, the short circuit current I_{sc}, the output power P_{out} and the optimum thickness of the subcell. The absorption coefficient of each subcell was modelled by using this equation [16] :

$$\alpha(\lambda) = 5.5\sqrt{E(\lambda) - E_g} + 1.5\sqrt{E(\lambda) - (E_g + 0.1)} \tag{2}$$

where $E(\lambda)$ is the photon energy of solar radiation at a particular wavelength and E_g the energy gap of the subcell. The power P is defined as the solar radiation intensity multiplied by the area of the solar cell. The total efficiency of the multijunction solar cells is calculated using :

$$\eta = \left(\frac{P_1 + P_2 + P_3}{P_0}\right) \tag{3}$$

where P_0 is the incoming power received by the first subcell, and P_1, P_2 and P_3 are the electric power produced by the first, second and the third subcells. Similar approach has been done in reference [17]. The temperature effect takes places in the single diode model (SDM) which governs the current producing simulation. Based on this model, for one sun radiation, the open circuit voltage V_{oc} is calculated through this equation :

$$V_{OC}(T) = \frac{nkT}{q}\ln(\frac{J_{SC}}{J_0(T)}) \tag{4}$$

where J_0 is the dark saturation current, J_{SC} is the short circuit current, k is the Boltzman constant, q is the electric charge and n is the number of flowing charge.
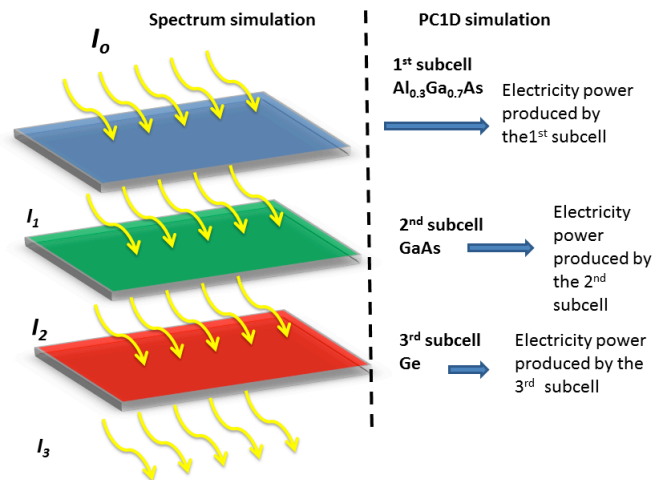
Figure 1. Ilustration of multijunction solar cells simulation.

3. Result and Discusions

The simulation results were shown in Table 1. The results of spectrum simulation for each subcell were shown in the incoming solar radiation intensity values. The amount of incoming AM1.5G solar radiation power per cm^2 received by the first subcell is 989.32x10^{-4} Watt, which is smaller than the solar constant 1353 x10^{-4} Watt. The transmitted radiation to the second subcell is 538.40 x10^{-4} Watt and to the third subcell was 335.80 x10^{-4} Watt. As the temperature of the subcell is increased, the amount of electrical power produced by each subcell became smaller. The same behavior also found in the V_{oc} of each subcell. In Figure 2, the V_{oc} of each subcell was decreased as the temperature increased as seen on Figure 2(a). The decreasing rate of V_{oc} for $Al_{0.3}Ga_{0.7}As$ subcell and GaAs were similar -1.4 mV/ºC. The I-V diagram in Figure 2(b) shows that the increasing temperature will reduced the overall electrical performance of multijunction solar cells.

Table 1. Simulation results

Subcell	Energy gap (eV)	Thickness (µm)	n dopping	p dopping	Incoming solar radiation power (x10^{-4} Watt)	Electric power produced in 1 cm^2 area at various temperatures (x10^{-4} Watt)			
						25 ºC	50 ºC	75 ºC	100 ºC
$Al_{0.3}Ga_{0.7}As$	1.817	2.91	1.00x10^{20}	1.00x10^{16}	989.32	450	436	422	408
GaAs	1.42	3.00	1.00x10^{17}	1.00x10^{16}	538.40	198	190	182	174
Ge	0.667	5.00	1.80x10^{17}	1.00x10^{16}	335.80	37	33	28.8	24.7

The features of our simulations are consistent with the experimental results of other III-V based multijunction solar cells. Aho *et al* [13] found that the V_{oc} of GaInP/GaAs/GaInNAsSb decreased by -7.5 mV/ºC and the total efficiency by -0.09%/ºC, while our results have shown a performance degradation of about -1.40 mV/ºC and-0.106%/ºC for $Al_{0.3}Ga_{0.7}As$/GaAs/Ge multijunction solar cells. Eventhough the systems are different, but in general the performance degradation of III-V based multijunction solar cells due to the increasing temperature lies within the same range of about -1.0 to -10.0 mV/ºC for V_{oc} and -0.10%/ºC for the total efficiency. The degradation rate of V_{oc} and the subcell efficiency of each subcell in our simulation is similar as shown

by proportional gradients in Figure 2(a) and Figure 3(a). The same behavior of III-V based solar cells due to the increasing temperature was also found in other reference [13,18]. Figure 3(b) shows the total efficiency degradation of $Al_{0.3}Ga_{0.7}As/GaAs/Ge$ with the degradation rate of -0.106%/^{o}C which is comparable to the result of others [13]. The lattice constant of $Al_{0.3}Ga_{0.7}As$, GaAs and Ge is 5.655 Å, 5.653 Å, 5.658 Å respectively [19]. With the average lattice mismatch of only 0.4%, the same monotonic behavior of each subcell is expected. The lattice matching arrangement of semiconductor materials in multijunction solar cells will minimize the dissipated power and allows a similar (monotonic) response in electrical performance and power efficiency of each subcell as shown in Figure 2(a) and 3(a).
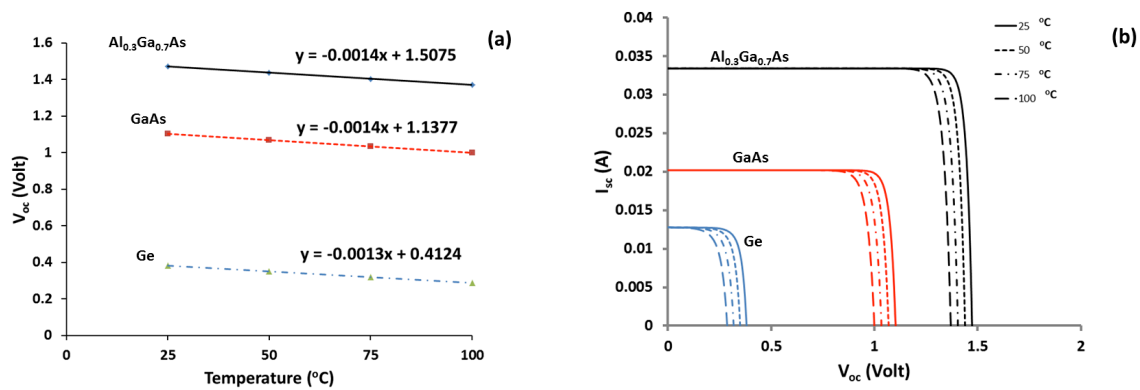

Figure 2. The thermal response of each subcell is shown in (a), while the performance of each subcell at various temperature (25 ^{o}C, 50 ^{o}C, 75 ^{o}C, 100 ^{o}C) is shown in (b).
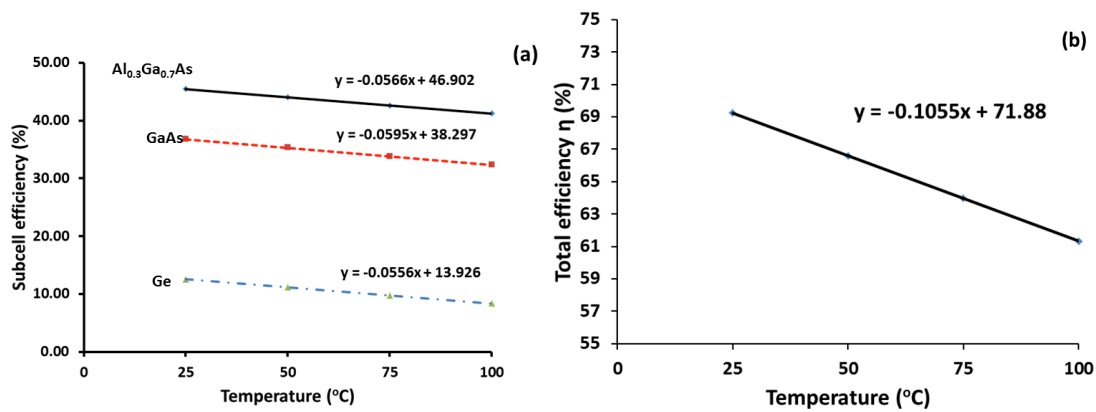

Figure 3. The efficiency degradation as a function of temperature for (a) each subcell, and for (b) the whole multijunction solar cells.

4. Conclusion

The study of temperature effect to the performance and the efficiency of $Al_{0.3}Ga_{0.7}As/GaAs/Ge$ multijunction solar cells has been performed. The increasing temperature of multijunction solar cells will reduce the performance and the efficiency as shown by the decreasing V_{oc} and the efficiency of

each subcell. Eventhough we use different system, but the general feature of our results is in a good agreement with the experimental results of other III-V based multijunction solar cells.

Acknowledgement

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