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The Effect of a Graded Band Gap Window on the Performance of a Single Junction $Al_xGa_{1-x}As/GaAs$ Solar Cell

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Abstract**—**We have modeled the effect of a graded band gap window on the performance of a single junction $Al_xGa_{1-x}As/GaAs$ solar cell. First, we study the electrical characteristics of a single junction $Al_xGa_{1-x}As/GaAs$ solar cell, by employing an optimized structure for this solar cell, we show that grading the band gap of the window can increase the conversion efficiency of the solar cell by about 1.5%, and can also improve the quantum efficiency of the solar cell especially at shorter wavelengths.

Keywords**—**Conversion efficiency, Graded band gap window, Quantum efficiency, Single junction $Al_xGa_{1-x}As/GaAs$ solar cell

I. Introduction

DIRECT gap III-V semiconductors are promising materials for both terrestrial and space solar applications such as satellites and spacecrafts due to their high conversion efficiency and high resistance to the radiation by high energy particles [1]. One of the best conversion efficiencies reported for a single junction GaAs solar cell under the global AM1.5 spectrum at 25°C is 26.1% [2].

Unfortunately GaAs solar cells suffer from carrier loss due to a high surface recombination velocity. In order to reduce such losses a wide band gap layer of $Al_xGa_{1-x}As$ is placed on top of the GaAs emitter to create a hetero-junction solar cell. With a wide band gap layer, minority carriers in the emitter undergo an additional force which prevents their motion back to the cell's top surface. This increases the cell's performance at shorter wavelengths [3].

In this paper, we first study the electrical characteristics of a single junction $Al_xGa_{1-x}As/GaAs$ solar cell, by employing an optimized structure for this solar cell, we show that grading the band gap of the window can increase the conversion efficiency of the solar cell by about 1.5%, and can also improve the quantum efficiency of the solar cell especially at shorter wavelengths. According to the best of our knowledge, this is the first time that such a usage of window on a single junction $Al_xGa_{1-x}As/GaA$ solar cell is presented.

II. Device analysis

In this section, we analyze a single junction $Al_xGa_{1-x}As/GaAs$ solar cell. A two dimensional simulator software was employed for this purpose. Consider a typical solar cell with p^+-$Al_xGa_{1-x}As$/p-GaAs/n-GaAs/n^+-GaAs configuration. Typically x value of the window layer is more than 0.8. The thickness of theses layers are 1, 2, 20 and 400 µm, and corresponding concentrations are 2×10^{18}, 2×10^{18}, 1×10^{17} and 1×10^{18} cm^{-3}. This solar cell has previously been fabricated, and experimentally shown that the short circuit current density and the open circuit voltage under AM0 spectrum and 1sun condition is about 22.8 mA/cm^2 and 1.02 V respectively [4]. To create AM0 spectrum in the simulator software, an input data base file consisting of pairs of wavelength and power was provided, the data base content was extracted from [5]. Short circuit current density and open circuit voltage resulted from simulation are 22.44 mA/cm^2 and 0.97 V respectively; minor differences may arise due to the variations in the material and optical parameters used. Theses parameters can easily be tuned to reflect experimental results more accurately.

Optimization of the above solar cell has previously been carried out [6]-[8]. Moreover, to increase the quantum efficiency and decrease the reflection coefficient, a layer of anti-reflection coating is used over the window. Anti-reflection coating is typically composed of one layer of a transparent insulating material that is one quarter optical wavelength thick, and significantly reduces reflectivity of light at the design wavelength. Refractive index, *n*, and thickness, *h*, of the anti-reflection coating are calculated from [9]:

$$n = \sqrt{n_1 n_2} \quad (1)$$

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$$h = \frac{\lambda}{4n} \quad (2)$$

Here, n_1 is the refractive index of air and n_2 is the refractive index of window layer. λ is the design wavelength and is assumed to be 0.6 μm.

Solar cell structure is shown in Fig. 1. Results obtained from numerical simulation for the case where the window is $Al_xGa_{1-x}As$ with x equals to 0.85 and the case where the window is $Al_xGa_{1-x}As$ with x varies from 0.85 to 0 under AM0 spectrum and 1sun condition is presented in Table I. Fig.2 shows JV characteristics of the single junction $Al_xGa_{1-x}As/GaAs$ solar cell for the two cases. It can be seen that grading the band gap of the window increases the short circuit current density from 31.7212 mA/cm^2 to 33.7314 mA/cm^2, and slightly increases the open circuit voltage from 1.00076 V to 1.00229 V. Fig.3 shows PV characteristics of the single junction $Al_xGa_{1-x}As/GaAs$ solar cell for the two cases. It is seen that grading the band gap of the window increases the maximum output power from 26.7909 mW/cm^2 to 28.8694 mW/cm^2. Fig. 2 and Fig.3 shows that grading the band gap of the window can improve the conversion efficiency by about 1.5%. Fig. 4 and Fig.5 represent the internal and external quantum efficiency versus optical wavelength of the single junction $Al_xGa_{1-x}As/GaAs$ solar cell for the two cases. We can see that grading the band gap of the window improves both the internal and external quantum efficiency especially at shorter wavelengths.

The increase in the conversion efficiency of the solar cell by about 1.5% and improvement of both internal and external quantum efficiency of the solar cell especially at shorter wavelengths may be attributed to the increase in the effective absorption coefficient of the graded band gap window. The absorption coefficient, α, is related to the extinction coefficient, k, by [10]:

$$\alpha = \frac{4\pi k}{\lambda} \quad (3)$$

Equation (3) shows that light with higher energy and shorter wavelength has higher absorption coefficient. The absorption coefficient is inversely proportional with the absorption depth, so light with higher energy and shorter wavelength has higher absorption coefficient and shorter absorption depth [10].

Effective absorption coefficient of a graded band gap layer is given by [11]:

$$\begin{aligned}
&\alpha_{eff} = 0 && 0 < h\nu < E_{gmin} \\
&\alpha_{eff} = \frac{2}{3}\alpha_{gmin}\left(\frac{h\nu - E_{gmin}}{E_{gmax} - E_{gmin}}\right) && E_{gmin} < h\nu < \frac{3}{2}(E_{gmax} - E_{gmin}) + E_{gmin} \\
&\alpha_{eff} = \alpha_{gmin} && \frac{3}{2}(E_{gmax} - E_{gmin}) + E_{gmin} < h\nu
\end{aligned} \quad (4)$$

α_{eff} is the effective absorption coefficient of the graded band gap layer, E_{gmin} and E_{gmax} are the minimum and maximum energy gaps of the graded band gap layer respectively, α_{gmin} is the absorption coefficient of the graded band gap layer at E_{gmin}, h is the Plank's constant and ν is the frequency of the incident light. Equation (4) shows that when the light energy increases, the effective absorption coefficient of the graded band gap layer approaches the absorption coefficient at E_{gmin}. The absorption coefficient is inversely proportional with the band gap energy [11]; thus, increase in the light energy cause an increase in the effective absorption coefficient of the graded band gap window.

Here, the depletion region width is 0.1 μm, the overall width of the graded band gap window and emitter layers is 0.33 μm, the average diffusion length of the minority carriers in the graded band gap window layer is 3.27 μm, and the diffusion length of the minority carriers in the emitter layer is 4.56 μm. We can see that, the diffusion length of the minority carriers in the graded band gap window layer is greater than the distance between the graded band gap window layer and the p-n junction. Thus, minority carriers which are created by the absorbed photons in the graded band gap window layer can be collected by the p-n junction, and contributed to the light-generated current [10]. Consequently, solar cell electrical characteristics will improve.

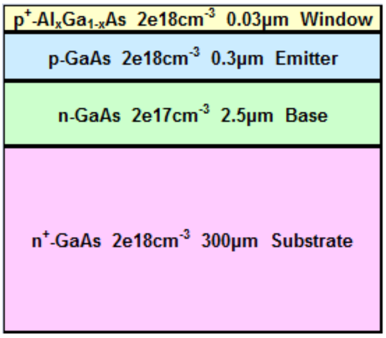

Fig. 1 Structure of the single junction $Al_xGa_{1-x}As/GaAs$ solar cell

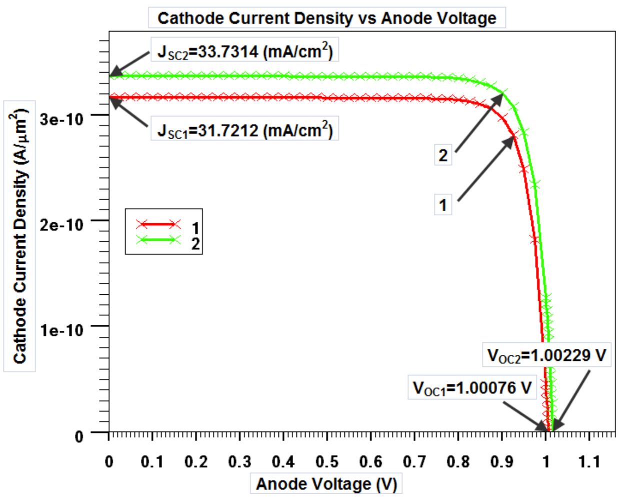

Fig. 2 JV characteristics of the single junction $Al_xGa_{1-x}As/GaAs$ solar cell (1) when x equals to 0.85, (2) when x varies from 0.85 to 0

TABLE I RESULTS OBTAINED FROM NUMERICAL SIMULATION OF THE SINGLE JUNCTION $AL_xGA_{1-x}AS$/GAAS SOLAR CELL FOR THE CASE WHERE THE WINDOW IS $AL_xGA_{1-x}AS$ WITH X EQUALS TO 0.85 AND THE CASE WHERE THE WINDOW IS $AL_xGA_{1-x}AS$ WITH X VARIES FROM 0.85 TO 0 UNDER AM0 SPECTRUM AND 1SUN CONDITION

Window	J_{sc} (mA/cm^2)	V_{oc} (V)	P_m (mW/cm^2)	V_m (V)	J_m (mA/cm^2)	FF (%)	E_{ff} (%)
$Al_xGa_{1-x}As$ x=0.85	31.7212	1.00076	26.7909	0.9	29.7677	84.3933	19.6229
$Al_xGa_{1-x}As$ 0<x<0.85	33.7314	1.00229	28.8694	0.9	32.0771	85.3906	21.1453

J_{SC}=Short Circuit Current Density, V_{OC}=Open Circuit Voltage, P_m=Maximum Output Power, V_m=Maximum Output Voltage, J_m=Maximum Output Current Density, FF=Fill Factor, E_{ff}=Efficiency.

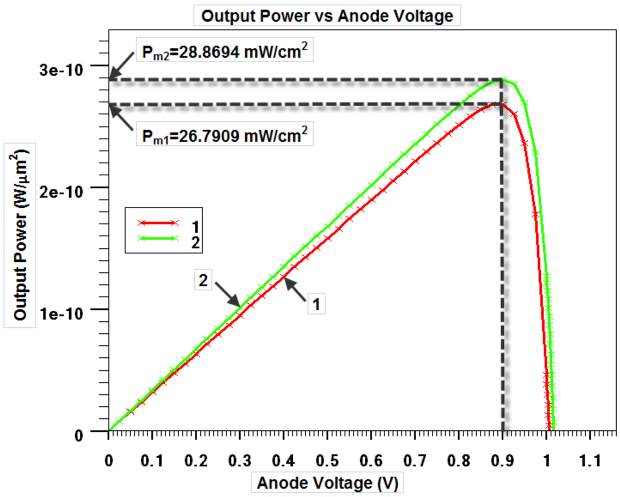

Fig. 3 PV characteristics of the single junction $Al_xGa_{1-x}As$/GaAs solar cell (1) when x equals to 0.85, (2) when x varies from 0.85 to 0

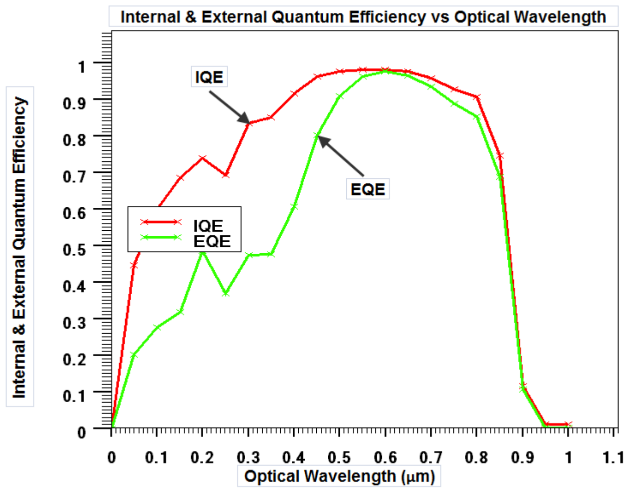

Fig. 5 Internal and external quantum efficiency versus optical wavelength of the single junction $Al_xGa_{1-x}As$/GaAs solar cell when x varies from 0.85 to 0

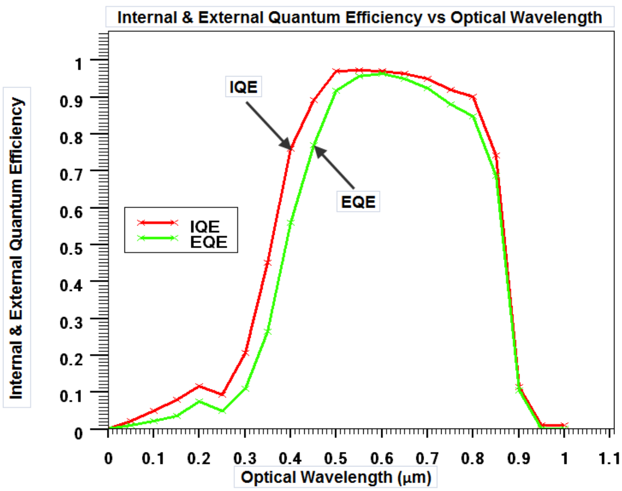

Fig. 4 Internal and external quantum efficiency versus optical wavelength of the single junction $Al_xGa_{1-x}As$/GaAs solar cell when x equals to 0.85

III. CONCLUSION

We have investigated the effect of a graded band gap window on the performance of a single junction $Al_xGa_{1-x}As$/GaA solar cell. By grading the band gap of the window material the effective absorption coefficient of the solar cell increases, and as a result, this enhances the conversion efficiency of the solar cell by about 1.5%. The quantum efficiency of the solar cell can also improve especially at shorter wavelengths.

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