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A NEW APPROACH TO IDEAL AlGaAs MQW SOLAR CELLS

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A theoretical model has been developed which shows that the insertion of multi-quantum wells into the depletion region of a p-i(MQW)-n $Al_xGa_{1-x}As$ solar cell can significantly enhance the conversion efficiencies. Open-circuit voltages, short-circuit current densities, I-V curves and conversion efficiencies have been calculated as functions of the well and barrier band gaps, width and depth of the wells, number of wells in the intrinsic region and the recombination rate in the interfaces. Particular emphasis is placed on calculation of absorption of the $Al_xGa_{1-x}As$ quantum wells. These results are matched with p-i-n solar cells which are identical in all respects except that they do not have quantum wells. We demonstrated that for determined values of the studied parameters the conversion efficiencies of the quantum well solar cell is higher to corresponding cell without quantum wells.

1 Introduction

The use of quantum wells to improve solar cell efficiencies has been the subject of a number of studies in recent years mainly by the Imperial College group in London [1, 2,]. Extending such efficiency enhancements to real practical solar cells depends in part on the optimization of cell design. Multi-quantum wells (MQW) are inserted into the intrinsic region of a wide gap p-i-n cell to ensure absorption of longer wavelengths, without the need for loss electrical connections. However, the quantum wells increase the carrier recombination and therefore the voltage is reduced. The net effect on efficiency, then, depends on whether the benefit to current outweighs the detriment to voltage.

In this work we report a theoretical model which shows that the insertion of multi-quantum wells into the depletion region of a p-i (MQW)-n $Al_xGa_{1-x}As$ solar cell can significantly enhance the conversion efficiencies. Open-circuit voltages (Voc), short-circuit current densities (Jsc), I-V curves and conversion efficiencies (η) are calculated as functions of the well and barrier band gaps, width and depth of the wells, number of wells in the intrinsic region and the recombination rate in the interfaces between well and barrier materials. Considering the light absorption by energy levels in the quantum wells we demonstrated that there are certain values of the studied parameters that enhance the efficiencies of the MQW well solar cell in comparision with conventional p-i-n solar cell.

2 Models

The current density of a conventional p-i-n solar cell of a band gap energy (Eg) can be written as a function of applied voltage (V) by the well-known Schockley equation for ideal diode to which the generation and recombination currents in the intrinsic region of carries created as product of the light incidence is added:

$$J(V) = J_0[\exp(qV/kT)-1] - J_G + J_R \quad (1)$$

where k is the Boltzman's constant, T is the absolute temperature, q is the electron charge, J_0 is the reverse saturation current densities, and J_G and J_R are the superposed current densities corresponding to carrier generation and recombination in the intrinsic region, respectively. The expressions for J_G and J_R are identical to those reported by Anderson in reference [3].

In the homogeneous AlGaAs p-i-n solar cells with band gap energy E_B, a fraction f_w of the intrinsic region is substituted by multi-quantum wells materials with lower Al composition and consequently with a narrower band gap E_A, resulting a p-iMQW-n solar cell. Modifying Eq. (1) to incorporate generation and recombination currents in both the wells and barriers yields:

$$J_{MQW} = J_0(1+r_R\beta)[\exp(qV/kT)-1] + (\alpha r_{NR} + r_s)[\exp(qV/2kT)-1] - qW\Phi \quad (2)$$

All the terms of the equation (2) are identical to the reported ones in reference [3], excepting :

$$r_s = 2Nqn_{iB}\gamma_{DOS}V_s\exp(\Delta E/kT) \quad (3)$$

where r_s and V_s are the recombination current and the superficial recombination rate at interfaces, respectively, $\Delta E = E_B - E_A$ and N is the number of wells in the intrinsic region. The meaning of the other terms can also be found in the reference [3].

The procedure to calculate de J-V curves and the solar cell efficiencies was the following. We initially took reported values the AM 1.5 solar spectrum and the Al_xGa_{1-x} As absorption coefficient. Below, we determined the energy levels in the quantum well as function of the its width and depth in order to calculate the absorption in the solar cell. Finally, we computed the J(V) relation using the eq. (1) and eq. (2) and we find the solar cell efficiencies considering a spectrally integrated one-sun intensity of 100 mW/cm^2.

3 Results and Discussion

Using the eq. (1) and eq. (2) we computed the J-V characteristics for the conventional AlGaAs p-i-n solar cell and AlGaAs p-i(MQW)-n solar cell, respectively. The parameters used in the calculation are shown in the table I.

Al composition in the well	x_w	0 to 0.35
Al composition in the barrier	x_b	0 to 0.35
Well width	L_w	1 to 10 nm
Well number	N	1 to satisfy MQW condition in the intrinsic region (1 μm)
Superficial recombination rate	V	30 to 300 cm/s

TABL E I. Selected parameter values used in the calculations.

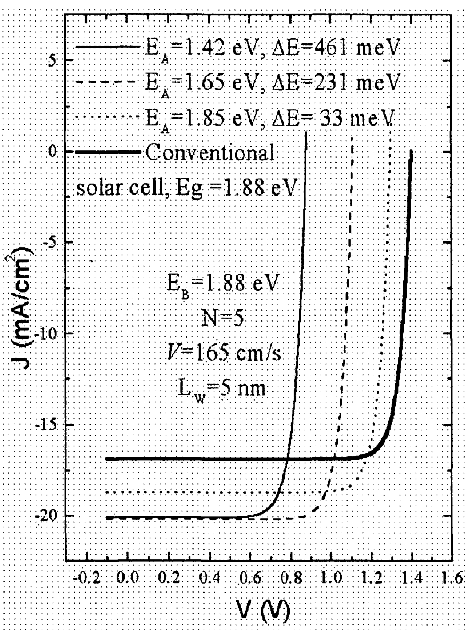

Fig. 1 J-V characteristics for MQW solar cell with different E_A values. Also the conventional solar cell is displayed.

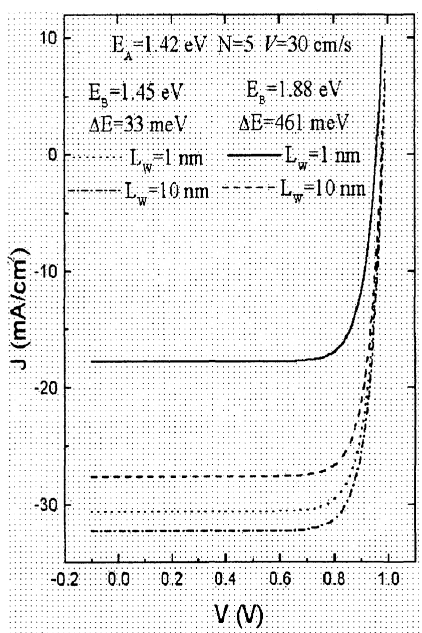

Fig. 2 J-V characteristics for MQW solar cells as a function of the quantum well with and the ΔE.

Figures 1 and 2 show the J-V characteristics for conventional and quantum well solar cells. Note in Fig. 1 that the conventional solar cell J-V characteristics has the greater value of Voc and the smaller of Jsc and introducing and deepening the quantum wells increases the Jsc and lowers the Voc. Fig. 2 shows the effect of the quantum well width in the J-V characteristics. Increasing Lw, the short circuit current also increase. Nevertheless the increase in Jsc is more remarkable when ΔE is greater, because there are more energy levels in the well. The interpretation of these awaited behaviors support the used procedure.

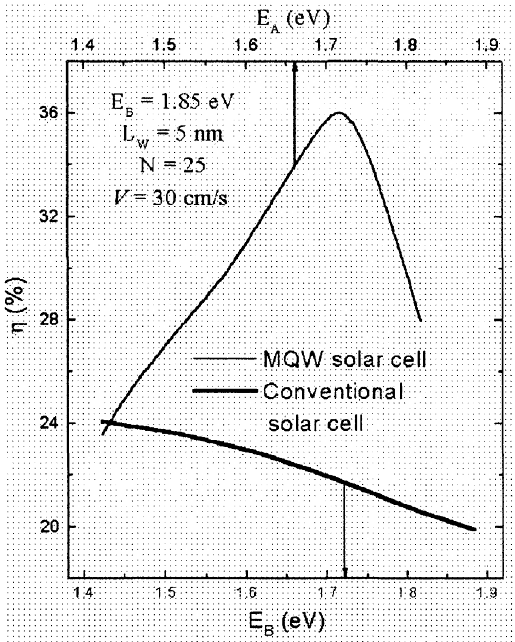

Fig. 3 MQW and conventional solar cell efficiencies as a function of the E_A and E_B, respectively..

Figure 3 displays the solar cells efficiencies as a function of the quantum well gaps for E_B = 1.88 eV. Note that the conversion efficiency reaches a maximum value around 1.72 eV. As E_A increases, the ΔE diminishes leading a monotonously increase of Voc. A quantum well depth reduction originates that more carriers in the well overcome the barrier increasing the Jsc, but at the same time a depth quantum well reduction causes a reduction of absorbed photons decreasing the Jsc. These two opposite effects are responsible of the maximum in the efficiency conversion value.

4 Summary

We have demonstrated that, the efficiency depends strongly on the energy value of the barrier band gap from which the quantum well depth is considered. We also showed the possibility that the quantum well solar cell conversion efficiencies are higher than the conventional solar cell formed from the well material, namely AlGaAs.

References

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