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Parameters comparison of p-i-n and quantum well solar cells

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Double gallium arsenide quantum wells (2QW) were inserted within $Al_xGa_{1-x}As$ barriers of the intrinsic layer of an ordinary solar cell. Structure parameters have strong influence on device performance and should be precisely controlled in order to obtain the enhancement of conversion efficiency. Computer simulations of solar cells were carried out by SimWindows program v. 1.5.0. Some parameters of optimized quantum well solar cells (QWSC) and reference p-i-n solar cell structures, like: series resistance R_s, shunt resistance R_{sh}, emission coefficients (n_1 and n_2), diffusion and recombination components of current (J_d and J_r) were compared.

Keywords: quantum well solar cells (QWSC), conversion efficiency, SimWindows.

1. Introduction

Solar cells with quantum wells (QWSC) attracted great attention of researchers a few years ago. The predicted values of conversion efficiency were 40–50% [1]. The application of quantum wells shifts the absorption edge of a conventional p-i-n solar cell, causes an increase in photocurrent generation in comparison with the solar cells composed of barrier material, and increases the output voltage according to solar cells made from well material [2]. In spite of many years of studies, multi-quantum well solar cells (MQWSCs) still have not reached the predicted values of efficiency. At present, efficiencies of MQWSCs do not exceed 20–25% [3]. The problem is mainly caused by strong dependence of solar cells performance on geometry, composition and number of quantum wells in a solar cell.

The absorption edge of the solar cell is determined by the width and depth of quantum wells. If applied wells are deeper, the photons with smaller energies are absorbed and higher photocurrent could be generated. But the application of deeper wells decreases the open-circuit voltage. The open-circuit voltage is also determined by the band gap of barrier material. A larger number of wells within the intrinsic region decreases the absorption edge and increases the photocurrent [1, 4, 5] but simultaneously reduces the open-circuit voltage [6].

In order to achieve the enhancement of the quantum well solar cell structure performance, it is required to perform an optimization of the geometry and composition of all layers of the structure and then to compare the parameters to those of classical p-i-n and MQW solar cells. The algorithm of the optimization was already described [6].

2. Device description

The GaAs wells and $Al_xGa_{1-x}As$ barriers were inserted within an ordinary p-i-n solar cell intrinsic layer. The basic p-i(MQW)-n structure with two quantum wells is shown in Fig. 1. The *n*+ GaAs:Si doped at 1×10^{18} cm^{-3} substrate and buffer layer were applied. The GaAs n-type emitter and GaAs p-type base were used. The dopant concentration is given in Fig. 1. Additionally, separating layers composed of $Al_{0.1}Ga_{0.9}As$ as barriers material were applied. The emitter layer was followed by

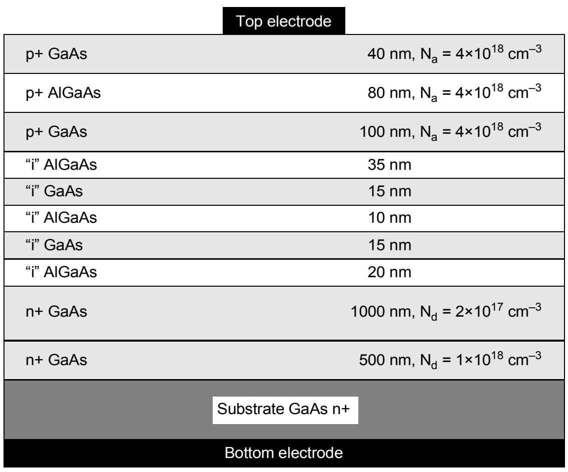

Fig. 1. Basic structure of MQWSC [6].

the $Al_xGa_{1-x}As$ window layer and the GaAs cap layer. Two reference p-i-n solar cell structures with an intrinsic layer composed of GaAs and $Al_{0.1}Ga_{0.9}As$ were also investigated for comparison purposes. Thickness of each intrinsic layer was equal to the sum of wells, barriers and separating layers thicknesses.

3. Structure parameters modelling

Double quantum well solar cell, p-i(GaAs)-n and p-i($Al_{0.1}Ga_{0.9}As$)-n structures were investigated. The dark J-V characteristics (Fig. 2) were simulated. The analysis of dark J-V plots enables us to evaluate the series and shunt resistances. It was also possible

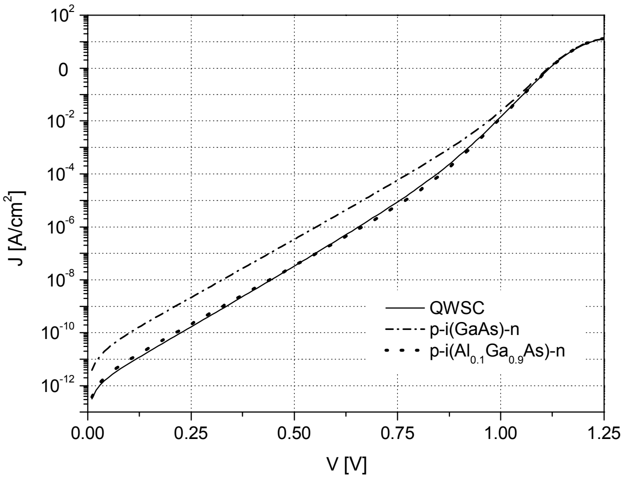

Fig. 2. Dark J-V characteristics of QWSC, p-i(GaAs)-n and p-i($Al_{0.1}Ga_{0.9}As$)-n structures.

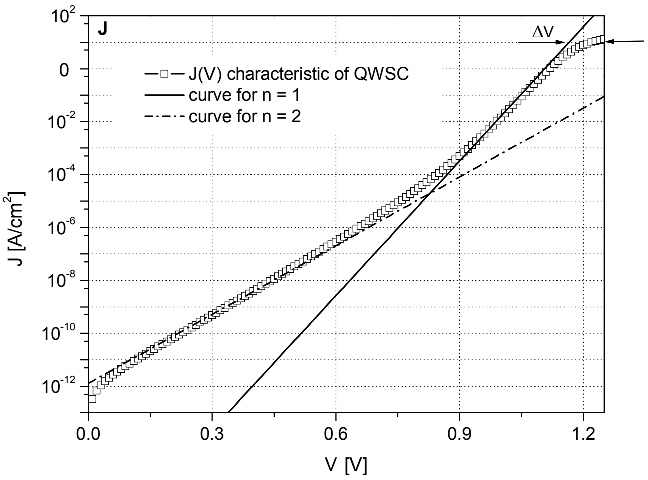

Fig. 3. Emission coefficients and series resistance evaluation of 2QWSC.

to calculate emission coefficients (n_1 and n_2) and diffusion as well as recombination currents of structures.

The method of evaluating emission coefficients and series resistance is shown in Fig. 3. Only 2QWSC characteristic is presented in Fig. 3, the other structures have similar plots. Emission coefficients were calculated with the use of Shockley's equation. Solid and dashed curves stand for emission coefficients values equal to 1 or 2. Calculated series resistances for all structures were approximately 47.3 mΩ. We have observed that the application of quantum wells does not influence the value of series resistance. The smallest emission coefficient n_1, equal to 1.07, was obtained for p-($Al_{0.1}Ga_{0.9}As$)-n structures, the largest value 1.25 was obtained for p-i(GaAs)-n solar cell. The emission coefficient of 2QWSC reached the value between the values of two examined p-i-n solar cell structures.

Unexpectedly, the largest emission coefficient n_2, equal to 1.99, was obtained for p-i(GaAs)-n structure. The smallest value of this parameter was observed for 2QWSC.

The diffusion J_d and recombination J_r components of the current were estimated from J-V dark plots. The application of quantum wells does not influence diffusion current, its value remains unchanged for all structures (see the Table). Recombination current has the highest value for p-i(GaAs)-n solar cell, what is closely related to the high value of n_2 coefficient.

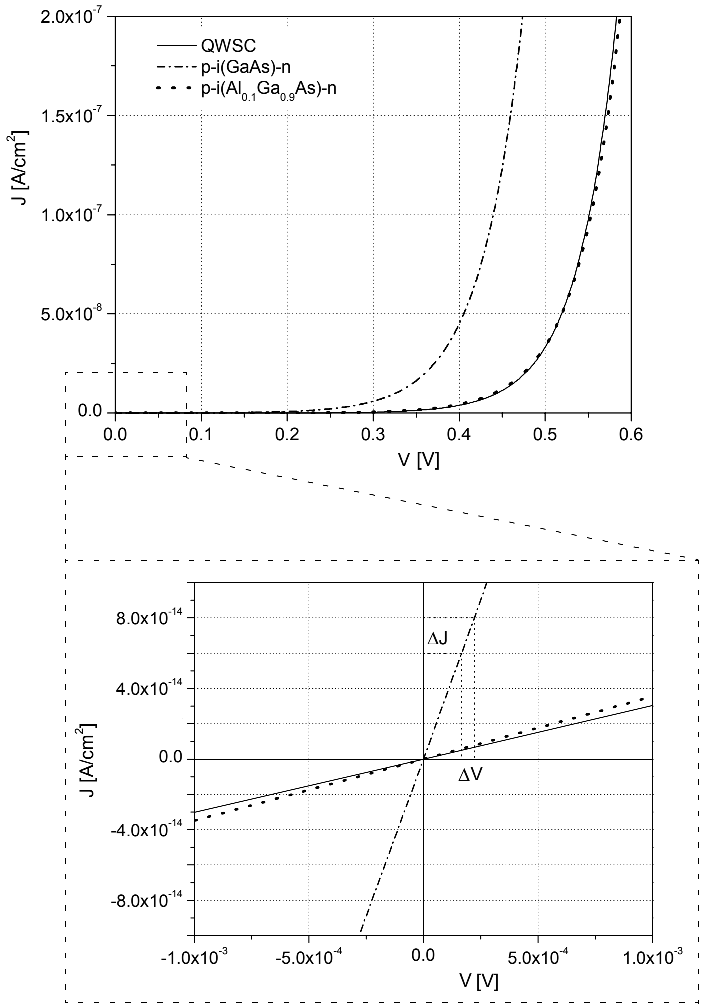

Fig. 4. Dark J-V characteristics for shunt resistance of p-i-n and QWSC calculation.

T a b l e. Evaluated parameters of QWSC, p-i(GaAs)-n and p-i($Al_{0.1}Ga_{0.9}As$)-n structures.

Structure description	R_s [mΩ]	R_{sh} [MΩ]	n_1	n_2	J_d [A/cm^2]	J_r [A/cm^2]
QWSC	47.3	29.4	1.13	1.87	2×10^{-19}	1.5×10^{-12}
p-i(GaAs)-n	47.3	2.6	1.25	1.99	2×10^{-19}	6×10^{-12}
p-($Al_{0.1}Ga_{0.9}As$)-n	47.3	23.5	1.07	1.97	2×10^{-19}	2×10^{-12}

Shunt resistance of p-i-n and QWSC was evaluated from the slop of initial part of dark J-V characteristics (Fig. 4). The resistance was calculated as the increment of voltage divided by the corresponding current increment. The highest value was obtained for QWSC and the lowest value was observed for p-i(GaAs)-n solar cell structure.

4. Conclusions

Modelling of solar cells was carried out by SimWindows program v. 1.5.0. As it has been shown earlier, an optimized quantum well solar cell has to contain GaAs quantum wells and $Al_{0.1}Ga_{0.9}As$ barriers in an intrinsic region. Modelling has been also performed for reference p-i-n solar cell structures with an intrinsic region composed of GaAs and p-i-n solar cell structure with $Al_{0.1}Ga_{0.9}As$ material. The parameters of analyzed 2QWSC and reference structures, like: series resistance R_s, shunt resistance R_{sh}, emission coefficients n_1 and n_2, diffusion and recombination components of current (J_d and J_r) were compared. We have observed that the application of quantum wells and further optimization of the solar cell structure do not influence the series resistance value. The improvement of other parameters, like shunt resistance and recombination current, has been observed. All mentioned above parameters have strong influence on conversion efficiency of the devices. According to the authors' observation, the most critical is an increase in R_s and decrease in R_{sh}, which significantly deteriorates conversion efficiency. The optimization of the solar cell structure parameters has to be carefully observed to obtain the enhancement of the conversion efficiency.

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