Enhanced Spectral Absorption in a-Silicon Photovoltaic Cell by Inserting c-Silicon Quantum Wells

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Abstract. Quantum well photovoltaic cells (QWPVCs) are heterostructure devices intended to achieve higher efficiencies than conventional cells. Generally this concept is used in well defined III-V material systems. This paper investigates effect on spectral absorption of amorphous silicon (a-Si) p-i-n photovoltaic cell because of inserting crystalline silicon (c-Si) quantum wells in the intrinsic layer. In this paper theoretical model is discussed and enhanced spectral absorption because of inserting quantum well structures inside the intrinsic layer of conventional amorphous silicon photovoltaic cell is reported. Control of the parameters is well within the thin film technological limits of present time.

1 Introduction

The QWPVCs are a special approach to multi-band gap solar cells where a multi-quantum well system is grown in the intrinsic region of a p-i-n structure [1, 2]. Various theoretical models have been developed to understand the performance of the QWPVCs and reviews of the theory have been published by Nelson [3], Barnham et al. [4] and Anderson [5]. The theoretical model developed for conversion efficiency enhancement of AlGaAs quantum well solar cells [6] is employed here to investigate the effect of inserting c-Si quantum wells into intrinsic layer of a-Si p-i-n photovoltaic cell. Present article suggests use of quantum well structures for widely used a-Si p-i-n photovoltaic cells in order to improve spectral absorption in the infrared region. In the present work available absorption coefficient data for c-Si [7] and extrapolated absorption coefficient data for a-Si [8] is used.

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2 Model

An a-Si/c-Si QWPVC with N_W wells each of length L_W in the intrinsic region of length W with barrier band gap Eg_B and well band gap Eg_W is studied. The external quantum efficiency (*EQE*) is an important parameter for calculating cell performance. The *EQE* for an ideal cell can be calculated using following expression [9]

$$EQE(E)=(-j_n(E)-j_p(E)-j_{dr}(E))/q \cdot b_s(E). \quad (1)$$

where, the current densities j_n, j_p and j_{dr} are due to n-, p- and depletion-regions respectively, $b_s(E)$ is the spectral photon flux and q is the electronic charge. The p- and n-region contribution to quantum efficiency can be classically evaluated by solving the carrier transport equations at room temperature within the minority carrier and depletion approximations [9]. The contribution of photo-generated carriers within the intrinsic region, i.e. j_{dr} to the *EQE* values is calculated by using the expression [6, 10]

$$EQE(E)=(1-R(E))\exp(-\sum \alpha_i z_i)[1-\exp(\alpha_B W - N_W \alpha_W L_W)]. \quad (2)$$

where, $R(E)$ is reflection coefficient, α_i is the absorption coefficient of *i*th layer from front side and z_i is the thickness of the same layer, α_B is the absorption coefficient of barrier layer, W is the thickness of intrinsic layer and N_W is the number of wells. A calculation of the quantum well intersubband absorption by electrons that occupy valleys with ellipsoidal constant-energy surface valid for indirect band gap semiconductors [11] is used for approximating α_W of the defined structure (with an assumption that crystalline silicon layer is (111) oriented).

The design parameters taken here as an example are just to understand the effect of insertion of quantum well layer because in this paper intention is to observe the effect of c-Si quantum well layer insertion not to work out an optimized design. The design of a-Si/c-Si QWPVC consists of c-Si (Eg_W = 1.1 eV) quantum wells of thickness 50 Å and a-Si (Eg_B =1.75 eV) barrier thickness 300 Å in the intrinsic layer of a-Si photovoltaic cell with assumed intrinsic layer thickness of 4500 Å, which is generally used for theoretical modelling. The p- and n- layer thicknesses are assumed to be 200 Å for this work, which again is taken with general modelling criterion. The calculations are performed using MATHEMATICA software. A schematic diagram consisting of p- layer, i-layer with single quantum well and n-layer is shown in Fig. 1. For results shown in the next section twelve quantum wells of mentioned thickness are taken.

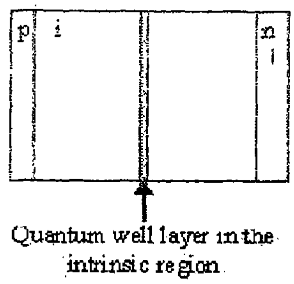

Fig. 1. Schematic diagram with single quantum well in the intrinsic layer.

3 Development of Silicon QWPVC

There may be several ways for the development of the silicon QWPVC. One simple method for the same is suggested here. The method includes sputtering process for the deposition of thin films. To develop p-i-n diode structure, the silicon may be sputtered in presence of diborane & argon (B_2H_6 + Ar for p-layer), hydrogen & argon (H_2 + Ar for i-layer) and phosphine & argon (PH_3 + Ar for n-layer) consequently. During deposition of intrinsic a-Si layer excimer laser crystallization approach may be used to create a thin layer of c-Si in the a-Si layer. Theoretical investigations as reported in this paper have shown that insertion improves the spectral response. Deposition parameters such as sputtering power, chamber pressure, substrate temperature, ratio of gases in the mixture, gas flow rates, excimer laser energy, and time duration for each layer deposition are the subjects of further study.

4 Results and Discussion

The results shown here are based on the calculations performed for the a-Si/c-Si QWPVC using available absorption coefficient data and the theoretical model presented in the previous section. For these calculations contribution of photo-generated carriers within the intrinsic region only to the *EQE* is considered and interface recombination is ignored. In Fig. 2, curve 1 represents the contribution of photo-generated carriers within the intrinsic region to the *EQE* of p-i-n amorphous silicon photovoltaic cell which covers a range of 1.36 – 3.5 eV. Curve 2 represents the contribution of photo-generated carriers within the intrinsic region to the *EQE* of a-Si/c-Si quantum well photovoltaic cell which covers a range of 1.1 – 3.5 eV. Two curves overlap in the region of 1.45 – 3.5 eV. It is evident from the Fig. 2 that curve 2 is extended in the lower energy side (in the ΔE region, i.e. from 1.1 to 1.36 eV) due to enhanced spectral absorption in a-Si photovoltaic cell by inserting c-Si quantum wells.

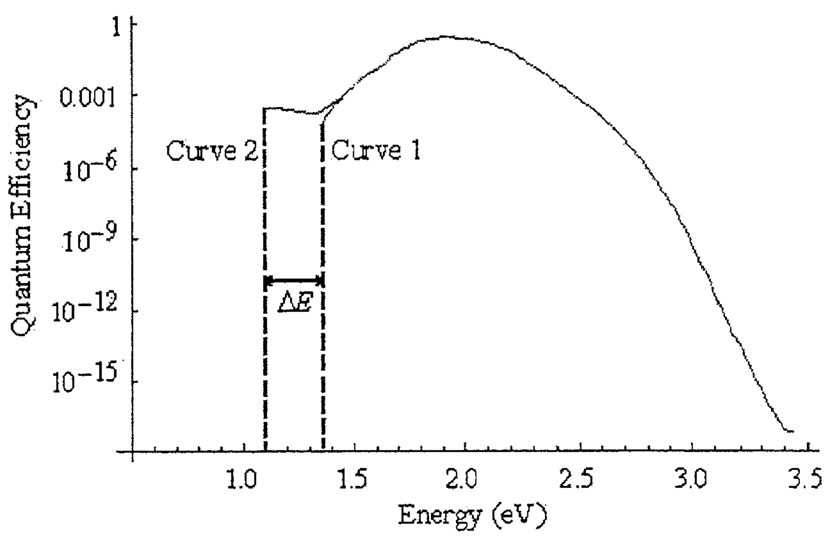

Fig. 2. Quantum efficiency Vs energy plot showing spectral absorption enhancement of QWPVC over a-Si PVC due to inserting c-Si quantum well.

5 Conclusion

Theoretical investigation is performed to study the effect of inserting a c-Si quantum well in the intrinsic region of a-Si p-i-n photovoltaic cell. It is concluded here that enhanced spectral absorption is observed because of inserting quantum well structures inside the intrinsic layer of conventional amorphous silicon photovoltaic cell. Further study is subject to the optimization of well and barrier layer thickness and actual deposition parameters.

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