Effect of the quasi-monocrystalline porous silicon (backside) on the photovoltaic parameters of thin silicon solar cell

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Abstract - Solar cells using quasi-monocrystalline porous silicon (QMPS) as an active device layer can fulfill the aim of low cost solar power and providing to obtain higher efficiency. In this paper, we considered an elementary solar cell of structure NPP’ consisted of two layers: monocrystalline silicon (regions N+ and P) and a backside thin film of heavily doped (P+) quasi-monocrystalline porous silicon. Every material was defined by its absorption coefficient. The continuity equations for the minority carriers are solved analytically for each region when the cell is illuminated. The results show an important effect of the quasi-monocrystalline porous silicon film on the thin silicon solar cell parameters. The highest cell efficiency was 21 %, showing an open circuit voltage of 670 mV, the short circuit current density was 38 mA/cm2 and the fill factor was 0.84.

1. INTRODUCTION

Thin film crystalline silicon solar cells on cheap Si-based substrates have a large potential in photovoltaic technology. Optical light confinement is a very crucial point of such thin film structures. QMPS layers as a perfect light diffuser could be used as a backside reflector [1].

In this paper, we study the solar cell model of structure NPP’ consisted of thin films crystalline silicon (regions N+P) with QMPS layer backside reflector (region P’); each is defined by its absorption coefficient. However, we conceived a model of a multilayer solar cell; the continuity equations for the minority carriers are solved analytically for each region when the cell is illuminated.

2. MODEL AND ANALYSIS

We consider an NPP’ solar cell structure, as illustrated in Fig. 1. For simplicity sake, a model of uniform spherical voids of identical size is considered, though there is a distribution of voids in actual QMPS layer [2].

The total short circuit current density Jsc of an elementary cell can be written as:

\[ J_{sc} = J_{sc1} + J_{sc2} + J_{sc3} \]

where \( J_{sc1} \) is the short circuit current density at the N+P junction. It is given by:

\[ J_{sc1} = -qD_{p} \frac{d\Delta p}{dx} \bigg|_{x=W_{e}} + qD_{n} \frac{d\Delta n}{dx} \bigg|_{x=W_{i}} \]

\( J_{sc2} \) is the short circuit current at the P-P’. It is given by:

\[ J_{sc2} = -qD_{n} \frac{d\Delta n}{dx} \bigg|_{x=W_{2}} + qD_{n}^{*} \frac{d\Delta n^{+}}{dx} \bigg|_{x=W_{2}} \]

\( \Delta p \), \( \Delta n \) and \( \Delta n^{+} \) are the excess minority carriers in the emitter, base and reflector regions respectively.

And \( J_{sc3} \) is the short-circuit in the depletion region at the N’P junction. It is given by:

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The continuity equation reduces to the diffusion equation for excess minority carriers in the different regions can be written as:

\[ D_{n,p,n^+} \frac{d^2 \Delta n, p, n^+}{dx^2} - \frac{\Delta n, p, n^+}{\tau_{n,p,n^+}} = -g(x) \]

where \( g(x) \) is the rate of generation of carriers at the point \( x \). In the monocrystalline silicon (regions \( N^+ \) and \( P \)) the electron-hole pair generation rate is modeled by:

\[ g(x, \alpha_i) = (1 - R) \sum_{i=1}^{n} \alpha_i \exp(-\alpha_i x) \]  

So in the QMPS (region \( P^+ \)) the electron-hole pair generation rate is modeled by:

\[ g^+(x, \alpha_i^+) = (1 - R) \sum_{i=1}^{n} \alpha_i^+ \phi_i \exp(-\alpha_i^+ x) \exp(-\alpha_i^+ (x - W_2)) \]

Theoretical models of the \( \alpha \) and \( \alpha^+ \) are reported in [3-4]. Also \( \phi \) is given by [5].

The boundary conditions for the short circuit case are as follows:

i) in the emitter region \( N^+ \)

\[ \left. \frac{d \Delta p}{dx} \right|_{x=0} = \frac{S_p}{D_p} \Delta p(x = 0) \quad \text{(a)}; \quad \Delta p(x = W_e) = 0 \quad \text{(b)} \]

ii) in the base region \( P \)

\[ \Delta n(x = W_1) = 0 \quad \text{(a)}; \quad \Delta n(x = W_2) = 0 \quad \text{(b)} \]

iii) in the reflector region \( P^+ \)

\[ \Delta n^+(x = W_2) = 0 \quad \text{(a)}; \quad \left. \frac{d \Delta n^+}{dx} \right|_{x=H} = -\frac{S_n^+}{D_n^+} \Delta n^+(x = H) \quad \text{(b)} \]

The total reverse saturation current density is expressed by:

\[ J_0 = J_{0e} + J_{0b} \]

where \( J_{0e} \) and \( J_{0b} \) are the conventional reverse saturation current density in the emitter and the base regions, respectively [6]. \( J_{0b} \) is defined by the effective surface recombination velocity at the back of P-base region [6-7].

The transport parameters like diffusion coefficient and lifetime of c-Si are reported in reference [8]. Also in the QMPS layer, these parameters are reported in [9].

Fig. 1: One-dimensional schematic model of an elementary solar cell with a QMPS layer on the backside
3. RESULTS AND DISCUSSION

The results of the photovoltaic parameters presented in this paper are computed using the following numerical values (Table 1).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_p$</td>
<td>cm.s$^{-1}$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>$S_n$</td>
<td>cm.s$^{-1}$</td>
<td>$10^4$</td>
</tr>
<tr>
<td>$W_e$</td>
<td>µm</td>
<td>0.3</td>
</tr>
<tr>
<td>$W_b$</td>
<td>µm</td>
<td>1</td>
</tr>
<tr>
<td>$N_d$</td>
<td>cm$^{-3}$</td>
<td>$2.1 \times 10^{20}$</td>
</tr>
<tr>
<td>$N_a$</td>
<td>cm$^{-3}$</td>
<td>$7.4 \times 10^{19}$</td>
</tr>
<tr>
<td>$N_a^+$</td>
<td>cm$^{-3}$</td>
<td>$10^{19}$</td>
</tr>
<tr>
<td>$R$</td>
<td>cm.s$^{-1}$</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Fig. 2 shows the variation of short circuit current density as a function of the cell thickness ($H$), with different values of void radius ($a$). These different curves show that the current density $J_{sc}$ of a thin silicon solar cell based on QMPS has been modified by value $a$. We notice from these curves, the contribution reach of a thin QMPS layer increase when the void radius decreases. The absorption by QMPS is more important when the values of voids radius are weak. Consequently, the minority carrier density in this region increases. Similarly, the conversion efficiency curve (Fig. 3) reflects more or less the same nature as $J_{sc}$.

Figs. 4 and 5 plot the variation of $J_{sc}$ and $\eta$ versus cell thickness and for different porosity values. It is clear that the short circuit current density and cell efficiency increase when the porosity of the QMPS layer increases. We notice that the carrier generated by thin film QMPS increases with the porosity.

In Table 2, the theoretical high performances of the QMPS layer acts as a back surface field (BSF) on the photovoltaic parameters of elementary solar cell has been determined. It can be seen from the table 2 that the QMPS layer has an important effect on the photovoltaic parameters of thin elementary cell.
Table 2: Influence of the QMPS layer on the photovoltaic parameters (H = 10 µm)

<table>
<thead>
<tr>
<th></th>
<th>J_{sc} (mA/cm²)</th>
<th>η (%)</th>
<th>V_{oc} (mV)</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>P⁺ (c-Si)</td>
<td>26.8</td>
<td>15.4</td>
<td>680</td>
<td>0.84</td>
</tr>
<tr>
<td>P⁺ (QMPS)</td>
<td>33.7</td>
<td>19.6</td>
<td>688</td>
<td>0.84</td>
</tr>
</tbody>
</table>

4. CONCLUSION

The theoretical study of a thin silicon solar cell with a QMPS layer on the back surface shows that the last improves the photovoltaic parameters compared to conventional (BSF) silicon solar cell (P⁺ is c-Si layer). This improvement depends on the physical parameters of the quasi-monocrystalline porous silicon layer (void radius and porosity).

REFERENCES