Study on Dynamic Model of Polycrystalline Silicon Photocell

Yanlin Tang, Sheng Yuan, Yun Liu and Xueke Wu

ABSTRACT

The silicon photocell is a common solar cell, and the single crystal silicon photocell is the best among them. But the polycrystalline silicon photocell has many advantages such as simple manufacturing process and low cost. To deeper understand the working principle of polycrystalline crystal silicon photocell and the factors that affect solar cell performance, the equivalent circuit of photocell are simulated by using Multisim Software and AMPS-1D software in this paper. On this basis, we made some experimental simulations, and analyzed the influence of the thickness, doping concentration, local density of states, the potential barrier of before and after contact surface, the HT-EBL and ET-HBL structure of polycrystalline silicon on its open circuit voltage, short circuit current, fill factor and conversion efficiency. The results show that the thickness, doping concentration, local density of states, the potential barrier of before and after contact surface, the HT-EBL and ET-HBL structure of polycrystalline silicon photocell will affect on the open circuit voltage, short circuit current, filling factor and conversion efficiency. The best polycrystalline crystal silicon photocell conversion efficiency could reach 12.384% after adding the before and after contact layer.1

INTRODUCTION

Solar energy is a kind of renewable energy, which has many advantages such as green environmental protection, no fuel consumption, no regional restriction and scale flexible. In recent years, it has got the favor of all countries and will become the backbone of energy in the world. In order to develop domestic photovoltaic

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industry, all countries adopted various preferential policies to rapidly develop the global photovoltaic industry. Photovoltaic output reached 136.7 GW in 2013 [1]. In 1954, the first piece of valuable solar cells was made by Bell laboratory [2, 3]. Since then, the large-scale application of solar energy becomes reality. The current solar photovoltaic cell basically has some kinds such as silicon photocell, nano-crystalline photocell, organic photocell and dye sensitized photocell [4-6]. Silicon photocell, including single crystal silicon, polycrystalline silicon and amorphous silicon photocell, is the most mature technology. The conversion efficiency of single crystal silicon photocell is highest and occupies the main market share. Because polycrystalline silicon materials used as photocell is mostly made up of single crystal silicon particles, its quality is worse than that of single crystal silicon, and its conversion efficiency lower than that of single crystal silicon. There are many grain boundaries between single crystal silicon particles, and it shows a defect effect and the carrier recombination center role [7, 8]. But the polycrystalline silicon photocell production cost is lower [9, 10], most of the time it is used as a substitute for single crystal silicon photocell. To measure the application value of a photocell, its quality factor is main parameter [4]. According to the influence factors of photocell[11], this paper mainly simulate and analyze in theory the influence of the thickness, doping concentration, local density of states, the potential barrier of before and after contact surface, the HT-EBL and ET-HBL structure of polycrystalline silicon on the four performance parameters of photocell such as open circuit voltage[12,13], short circuit current [12,13], filling factor [4, 12,13] and conversion efficiency [13]. It could provide theoretical basis to improve the performance of polycrystalline silicon photocell.

THE EXPERIMENTAL SIMULATION

The main material in polycrystalline silicon photocell is silicon material, its forbidden band width, dielectric constant, electron affinity, electron hole mobility is the same as single crystal silicon. The influence of the thickness, doping concentration, local density of states, the potential barrier of before and after contact surface, the HT-EBL and ET-HBL structure of polycrystalline silicon on the four performance parameters of photocell were simulated and analyzed by AMPS - 1 d software under the conditions of DOS mode, homogeneous structure, 300 k, AM1.5 spectrum. The simulation parameters of polycrystalline silicon photocell are shown in table 1.

The simulation results show that the silicon photocell of short circuit current ISC =11.8mA/cm2, open circuit voltage UOC=0.43V, fill factor FF=0.74 and maximum conversion efficiency \( \eta = 3.8\% \). Best polycrystalline silicon photocell is that the thickness of P layer is 200 nm, thickness of N layer 50 um, doping concentration of P and N layer 1×1020cm-3. The effect of thickness and doping concentration of P
and N layer on polycrystalline silicon solar cell is the same with mono-crystalline silicon solar cells.

### TABLE I. EXPERIMENTAL SIMULATION PARAMETERS.

<table>
<thead>
<tr>
<th>Classification</th>
<th>P layer</th>
<th>N layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness /nm</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Relative dielectric constant</td>
<td>11.9</td>
<td>11.9</td>
</tr>
<tr>
<td>Electron affinity</td>
<td>4.05</td>
<td>4.05</td>
</tr>
<tr>
<td>Band gap of mobility</td>
<td>1.12</td>
<td>1.12</td>
</tr>
<tr>
<td>Optical forbidden band gap</td>
<td>1.12</td>
<td>1.12</td>
</tr>
<tr>
<td>Electron mobility</td>
<td>1350</td>
<td>1350</td>
</tr>
<tr>
<td>Hole mobility</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Doping concentration NA</td>
<td>1×10^{15}</td>
<td>0</td>
</tr>
<tr>
<td>Doping concentration ND</td>
<td>0</td>
<td>1×10^{15}</td>
</tr>
<tr>
<td>Effective state density of conduction band NC</td>
<td>(2.8\times10^{19})</td>
<td>(2.8\times10^{19})</td>
</tr>
<tr>
<td>Effective state density of valence band NV</td>
<td>(1.04\times10^{19})</td>
<td>(1.04\times10^{19})</td>
</tr>
<tr>
<td>Characteristic energy of conduction band tail EA</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Characteristic energy of valence band tail ED</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>the valence band tail state density (GDO)</td>
<td>(1\times10^{14})</td>
<td>(1\times10^{14})</td>
</tr>
<tr>
<td>the conduction band tail state density (GAO)</td>
<td>(1\times10^{14})</td>
<td>(1\times10^{14})</td>
</tr>
</tbody>
</table>

### THE INFLUENCING FACTORS OF POLYCRYSTALLINE SILICON SOLAR CELL

#### The Influence of Tail State Density

The distribution of tail state density is exponential, gap localized state density evenly distribution. The tail states density of valence band and conduction band are that

\[
g_a(E) = G_{ao} \exp \left( \frac{E - E_C}{E_a} \right) \tag{2}
\]

\[
g_d(E) = G_{do} \exp \left( \frac{E - E_V}{E_d} \right) \tag{1}
\]

There \(E_a\), \(E_d\) is the characteristic energy of conduction band (acceptor) tail state and valence band (donor) tail states, respectively. \(E\) is the energy for somewhere at tail. Each simulation was carried out from \(1\times10^{14}\text{cm}^{-3}\text{eV}^{-1}\)~\(1\times10^{23}\text{cm}^{-3}\text{eV}^{-1}\) at each order of magnitude of GDO and GAO, respectively. The simulation results are in following figure 1.

From figure 1, it can be found that the change of four performance index conversion such as the efficiency of photovoltaic cells, filling factor, open circuit...
voltage and short circuit current were not big along with GDO increased, but they had obvious decline when their increase reaches a certain value. The best tail state density GDO of photocell should be below $1 \times 10^{20}$ cm$^{-3}$ eV$^{-1}$.

Simulation also found that the four cell performance index change is not big as GAO increases. But when GAO reaches a certain value, the conversion efficiency of the battery, filling factor, open circuit voltage and short circuit current will have obvious drop. The best tail state density GAO of photocell should be under $1 \times 10^{20}$ cm$^{-3}$ eV$^{-1}$.

The Influence of Gap Localized State Density

In front of the silicon homogeneous junction photocell, the gap localized states with uniform distribution are adopt, and assume that the gap localized state density of acceptor and donor GMGA=GMGD=$1 \times 10^{14}$ cm$^{-3}$ eV$^{-1}$. Simulation are carried for each order of magnitude values of GMGA and GMGD from $1 \times 10^{11}$ cm$^{-3}$ eV$^{-1}$ to $1 \times 10^{18}$ cm$^{-3}$ eV$^{-1}$. The simulation results show that the change of conversion efficiency, filling factor, open circuit voltage, short circuit current four performance index is not big as GMGD, GMGA increased. But when the GMGA and GMGD reach a certain value, the four performance index will have obvious drop. The best GMGD and GMGA of photocell should be under $1 \times 10^{15}$ cm$^{-3}$ eV$^{-1}$.

Localized state is caused by a defect in a cell. The localized state in the solar cell between the gap play the role of composite carrier. When the concentration increase, the carrier compound enhance, thus the performance of the photovoltaic cells will reduce, which are in conformity with the simulation results.

The Influence of Before Contact $\Phi_{bo}$ And After Contact $\Phi_{kl}$

The influence of front interface potential barrier height parameter $\Phi_{bo}=Ec - EF$ on polycrystalline silicon photocell four performance index is simulated. It is found
that the four performance index of polycrystalline silicon solar cells is increasing along with $\Phi_{bO}$ increasing. When the $\Phi_{bO}$ arrived at 1.08 eV, the four performance index of polycrystalline silicon solar cell rapid increase. The change curve of the size of potential barrier with take barrier height parameter $\Phi_{bO}$ on the front interface is shown in figure 2 (a) by taking the built-in electric field direction for negative. It can be seen that the potential barrier is positive which hinders the collection of hole in the contact end drifting to P region through the built-in electric field as $\Phi_{bO} < 1.08$ eV. When the barrier is negative and larger, it is helpful for collecting these holes in the contact end.

The influence of back-interface potential barrier height parameter $\Phi_{bL} = E_c - EF$ on polycrystalline silicon photocell four performance index is simulated. It is found that the four performance index of polycrystalline silicon solar cells is decreasing along with $\Phi_{bL}$ increasing. When the $\Phi_{bL}$ arrived at 0.58 eV, the efficiency of photovoltaic cells, filling factor and open circuit voltage of polycrystalline silicon solar cell quickly reduce. The change curve of the size of potential barrier with take barrier height parameter $\Phi_{bL}$ on the back-interface is shown in figure 2 (b) by taking the built-in electric field direction for negative. It can be seen that the potential barrier is positive as $\Phi_{bL} > 0.16$eV. And the contact barrier increases constantly with the increase of $\Phi_{bL}$, which hinders the collection of electron in the contact end drifting to N region through the built-in electric field. Only when the barrier is negative and larger, it is helpful for collecting these electrons in the contact end and appears the four performance index of polycrystalline silicon solar cells decreasing with the increase of $\Phi_{bL}$.

**The Influence of Electronic - Hole Recombination Speed on Before Contact Surface**

The simulation results of electron recombination velocity on front surface to the four indicators of polycrystalline silicon photocell show that the light raw carrier compound of the former contact increases with the electron recombination velocity in front surface increasing. It is not conducive to collect the former contact carrier and reduces the solar cell performance. In order to get high performance of polycrystalline silicon photocell, we should try to make electronic composite speed
Figure 2. Change of the potential barrier of the front interface $\Phi_bO$ and back interface $\Phi_b$.

Figure 3. The solar cell structure with adding the HT - EBL and ET – HBL.

decreases and can add the structure layer allowing hole or electron to pass through respectively at front interface and back interface. Simulation results show that the performance of the photovoltaic cells have a lot of ascension as adding 40 nm thick layer of HT - EBL (only allow hole through, does not allow electronic through) in front interface and 40 nm thick layer of ET - HBL layer (only allow electronic through, do not allow the hole through) in back interface (see figure 3). The improved polycrystalline silicon photocell has short circuit current $I_{SC} = 28.403 \text{mA/cm}^2$, open circuit voltage $V_{OC} = 0.553 \text{V}$, fill factor $FF = 0.789$ and conversion efficiency $\eta = 12.384\%$.

DISCUSSION AND CONCLUSION

Based on simulating and analyzing the influence of the thickness, doping concentration, local density of states, the potential barrier of before and after contact surface, and of the polycrystalline silicon photocell on the cell performance parameters, it was found that: (1) When the GDO and GAO are less than $1 \times 10^{20} \text{cm}^{-3} \text{eV}^{-1}$, the polycrystalline silicon solar cells will have better performance parameters for the tail state density of donor and acceptor. (2) When the value of GMGD and
GMGA are less than $1 \times 10^{15} \text{cm}^{-3} \text{eV}^{-1}$, the polycrystalline silicon photocell will have high performance parameters for the gap state density of donor and acceptor. (3) When the before contact is greater than 1.08 eV and after contact less than 0.16 eV, the polycrystalline silicon solar cells will have good performance. (4) It should try to reduce the electron recombination at the surface for N layer and reduce the hole recombination at the surface for P layer. (5) When adding 40 nm thick layer of HT-EBL in front interface and 40 nm thick layer of ET-HBL layer in back interface, it can improve performance of the photovoltaic cells. The improved polycrystalline silicon photocell has short circuit current $I_{SC} = 28.403 \text{mA/cm}^2$, open circuit voltage $V_{OC} = 0.553 \text{V}$, fill factor $FF = 0.789$ and conversion efficiency $\eta = 12.384\%$.

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REFERENCES