Influence of Absorption Layer Thickness on the Performance of CIGS Solar Cells

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Abstract. As solar light was mainly absorbed by absorb layer in thin film solar cells, the quality of absorb layer has a great effect on the performance of solar cells. Based on the diffusion drift model of carrier in copper indium gallium selenide (CIGS) solar cells, and then the key parameters are analyzed. Combining with the experimental results of others, this paper discusses the absorption layer’s thickness influence on the open circuit voltage, short circuit current, filling factor and conversion efficiency of the copper indium gallium selenium based solar cells. The results show that the absorption layer’s thickness always affects the performance parameters of the battery. Open circuit voltage increased with increasing thickness and reached saturation above 2µm. Short circuit current increased first and then decreased, then reaches its maximum value at about 2µm thickness. Conversion efficiency is similar to the short circuit current properties. While the fill factor decreased with the increase of thickness above 1.2µm. This can provide theoretical support for the design of better device structures.

1. Introduction
The CuInGaSe (CIGS) based solar cells is composed of three main layers :Ga is doped into CuInSe2 to form CuIn1-xGaxSe2 to adjust its semiconductor band gap in the range of 1.04-1.65 eV as absorber layer, CdS as buffer layer, ZnO as the window layer. It has strong light absorption, no photoinduced decay effect, low production cost, good power generation stability, photoelectric conversion efficiency ranks first among thin film solar cells, which has aroused great interest of researchers [1-2]. At the same time, its adjustable band gap and low production cost also attracted researchers to use CIGS and dye-sensitized cells to form a laminated solar cell, which can improve the performance of open-circuit voltage, short-circuit current and conversion efficiency [3].

The preparation methods of absorption layer CIGS include magnetron sputtering-selenium method, co-evaporation method, electrochemical deposition method and chemical solution method. Different preparation methods and technological conditions affect the performance of the cell [4-6]. The characteristics of battery materials under different fabrication processes and conditions are represented by defects and their densities. The types, locations, densities and distributions of defects in different layers of battery materials are taken as parameters to characterize the performance of battery materials. Based on the carrier drift-diffusion model, two physical models, defect-assisted tunneling and in-band,
are added to simulate the open circuit of battery. Device performances of open voltage, short circuit current, filling factor and conversion efficiency have been optimized [7]. It can be used in battery test data analysis, device mechanism interpretation, and battery structure optimization and so on.

The thickness of ZnO/CdS layers is fixed at 0.2, 0.05µm. The defect of window layer ZnO is mainly donor-like, which is Gaussian distribution at the energy of 1.65eV with 0.1eV deviation. The defect of buffer layer CdS is mainly acceptor-like, which is Gaussian distribution at the energy of 1.2eV with 0.1eV deviation. The defect of absorption layer CIGS is mainly donor-like, which is Gaussian distribution at the energy of 0.6eV with 0.1eV deviation. The characteristics of the open circuit voltage, short circuit current, filling factor and conversion efficiency were obtained with simulation of current-voltage curve (I-V) curve of CIGS solar cells with variety of CIGS thickness.

2. Calculations

Parameters of CIGS solar cell were obtained from the current-voltage characteristic curve of the battery, which based on the solution of Poisson equation and electron-hole continuity equation. The Possion equation is as following:

\[ \frac{d}{dx} (\varepsilon(x) \frac{d\varphi}{dx}) = q \left[ p(x) - n(x) + N_{a}^{+}(x) - N_{d}^{+}(x) + p_{i}(x) - n_{i}(x) \right] \]  \hspace{1cm} (1)

And the continuity equations of electron and hole are expressed as following equation (2) and equation (3):

\[ \frac{dp}{dx} = G_{n} - \frac{p_{n} - p_{n0}}{\tau_{p}} - \frac{\mu_{p}}{\tau_{n}} \frac{d\xi}{dx} - \mu_{n} \frac{dp}{dx} + D_{p} \frac{d^2p}{dx^2} \]  \hspace{1cm} (2)

\[ \frac{dn}{dx} = G_{n} - \frac{n_{p} - n_{p0}}{\tau_{n}} + \frac{\mu_{n}}{\tau_{p}} \frac{d\xi}{dx} + \mu_{p} \frac{dn}{dx} + D_{n} \frac{d^2n}{dx^2} \]  \hspace{1cm} (3)

Where \( \varphi \) is the electrostatic potential, \( p_{i} \) and \( n_{i} \) are the composite center electron and hole concentration respectively; \( N_{a}\) is the acceptor like doping concentration of ionization; \( N^{+}_{d} \) is the donor like doping concentration of ionization; \( \xi \) is the electric field; \( p_{n} \) is the minority carrier (hole) concentration in n-type semiconductor; \( \tau \) is the minority carrier (electron) concentration in p-type semiconducting body. The above parameters are all related to the coordinate position \( x \) of CIGS solar cells. \( G \) denotes carrier generation rate, \( \tau \) denotes carrier lifetime, \( \mu \) is carrier mobility, \( \varepsilon \) denotes dielectric constant, \( D \) denotes carrier diffusion coefficient, and \( q \) denotes electron charge.

In this work, traditional ZnO/CdS/CIGS solar cells are used. Among them, ZnO is window layer, CdS is buffer layer, CIGS is absorption layer, CIGS is weak p-type, CdS is n-type. The parameters of ZnO, CdS and CIGS materials in batteries are shown in Table 1.

| Parameter | ZnO | CdS(n) | CIGS |
|-----------|-----|--------|------|
| Dielectric constant | 9 | 10 | 13.6 |
| Band gap (eV) | 3.3 | 2.4 | 1.15 |
| Electron affinity (eV) | 4.4 | 4.2 | 4.5 |
| \( N_{c} \) (cm\(^{-3}\)) | 2.2e18 | 2.2e18 | 2.2e18 |
| \( N_{d} \) (cm\(^{-3}\)) | 1.8e19 | 1.8e19 | 1.8e19 |
| \( \mu_{n} \) (cm\(^{2}\).V\(^{-1}\).s\(^{-1}\)) | 100 | 100 | 100 |
| \( \mu_{p} \) (cm\(^{2}\).V\(^{-1}\).s\(^{-1}\)) | 25 | 25 | 25 |
| \( N^{+}_{d} \) (cm\(^{-3}\)) | 1e18 | 1e18 | 0 |
| \( N_{i} \) (cm\(^{-3}\)) | 0 | 0 | 2e16 |
3. Results and discussion
The current-voltage relationship, electric field distribution, generation and recombination of carriers, carrier lifetime, band structure, free electrons and trapped electrons concentration, defect distribution and other device structures are calculated under the irradiation of AM1.5 standard solar energy spectrum at 300 K at room temperature. Current density \( J \) under different voltage \( V \) is simulated. According to the current-voltage (I-V) curve of the battery as shown in Figure 1, four parameters of the battery, open circuit voltage, short circuit current, fill factor and conversion efficiency, can be obtained.

![I-V curve of solar cell](image)

**Figure 1.** I-V curve of solar cell

In Figure 1, short circuit current \( I_{SC} \) is the intersection of I-V curve and I axis, and open circuit voltage \( V_{OC} \) is the intersection of curve and V axis. \( I_{mp} \) and \( V_{mp} \) are the current and voltage at the maximum power point of the battery. The filling factor (FF) and conversion efficiency (FF) are derived from the following equations (4) and (5):

\[
\text{FF} = \frac{I_{mp} \cdot V_{mp}}{V_{OC} \cdot I_{SC}}
\]  

\[
\eta = \frac{V_{mp}}{P_{in}}
\]

Where FF and \( \eta \) denote the fill factor and conversion efficiency, respectively. \( I_{mp} \) and \( V_{mp} \) denote the current and voltage values at the maximum power point, and \( P_{in} \) denotes the incident power.

In order to optimize the structure design of the battery, I-V curve characteristics of the absorption layer battery with different thickness were calculated and simulated. Then the four parameters of the battery, open circuit voltage, short circuit current, fill factor and conversion efficiency, can be obtained with variety of absorber thickness.
Figure 2. Open circuit voltage versus thickness of CIGS absorber

Figure 2 is the curve of open circuit voltage with an absorber thickness range 1 to 9µm. And we can see that with the thickness increases, the open circuit voltage increases, and the open circuit voltage finally reaches saturation basically above the thickness of 2µm. Which means the thickness of 2-3µm absorption layer was suggested for the CIGS solar cells for large open circuit voltage.

Figure 3. Short circuit current versus thickness of CIGS absorber

Figure 3 is the curve of short circuit current with an absorber thickness range 1 to 9µm. And we can see that with the thickness increases, the short circuit current increases first and then decreases. Short circuit current reaches its maximum at about 2µm thickness. Which means the thickness of around 2µm absorption layer was suggested for the CIGS solar cells for maximum short circuit current.
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4. Conclusion
Based on Poisson equation and electron-hole continuity equation, the current-voltage curve (I-V) characteristics of copper-indium-gallium-selenium (CIGS) based solar cells under normal temperature illumination were simulated, and the key parameters such as open-circuit voltage, short-circuit current, filling factor and efficiency were analyzed. The simulation is based on influence of absorption layer thickness on four the key parameters of open-circuit voltage, short-circuit current, filling factor and efficiency.
conversion efficiency. Calculations show that the thickness the absorbing layer always affects the performance parameters of the battery. Calculations indicated that the absorption layer’s thickness always affects the performance parameters of the battery. Open circuit voltage increased with increasing thickness and reached saturation above 2µm. Short circuit current increased first and then decreased, then reaches its maximum value at about 2µm thickness. Conversion efficiency is similar to the short circuit current properties. While the fill factor decreased with the increase of thickness above 1.2µm. In summary, thickness of absorption layer range 2 to 3µm was suggested for the optimization of CIGS solar structure.

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