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Research Article

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Effect of the Grain Boundary Shape on the Characteristics of the Multicylinder Crystal Solar Cell

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Abstract In this work, we have studied the dependence of the minority charge carrier lifetime and electrical characteristics on the shape of the grain boundaries of the multicylinder polycrystalline solar cell. Hence, we have first presented the continuity equation of the minority charge carriers of the solar cell base in the presence of defects and impurities at the grain boundaries. After solving the equation, we established new expressions for the minority charge carrier density, the photo-current density, the photo-voltage density and the charge carrier lifetime, all of which depend on the density of interface states at the grain boundaries. These results obtained after evaluation showed that the deformations of the electronic states at the grain boundaries have a compromising effect on the performance of the multicylinder grain solar cell.

Keywords solar cell, multicylinder grains, grain boundaries, lifetime, polycrystalline

1. Introduction

Polycrystalline silicon is a very abundant and promising technology for low cost solar cell production [1]. It is very efficient for terrestrial photovoltaic applications [1]. However, polycrystalline silicon substrates suitable for such an application must have a columnar structure formed by the juxtaposition of silicon grains limited by grain boundaries [2, 3]. In addition, the electrical parameters of photovoltaic solar cells are driven by factors including the quality of the intra-grain material [4], the surface finish and the properties of the grain boundaries [5]. For these factors, grain boundaries have a constraining contribution to production, reducing the performance of the solar cell [6]. In order to evaluate the influences of grain boundaries on the performance of polycrystalline solar cells, the continuity equation of the minority charge carriers in the cell base has to be solved [7].

Using 3D modelling analysis, the authors have shown that grain size has a positive effect on the electrical characteristics of the cell [8, 9]. On the other hand, others have revealed that the recombination rate at grain boundaries is compromising to the internal electrical activity of the cell [10, 11]. Using a new approach that involves the shape of the grain boundaries of a polycrystalline multi-cylinder grain solar cell, we investigate the density of interface states at the grain boundaries on cell output.

2. Theoretical study:

The study focuses on a polycrystalline multi-cylinder grain solar cell which is shown in Figure 1 below [4, 8]:

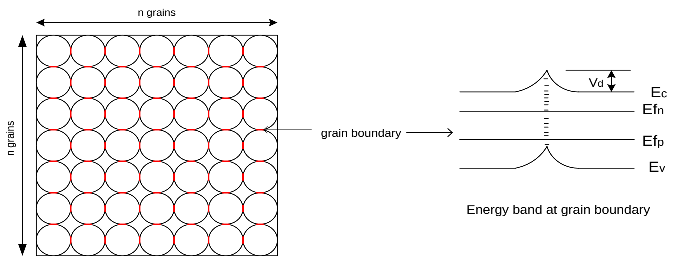

Figure 1: Multicylinder grain solar cell

When the cell is illuminated with multispectral white light and subjected to the action of grain boundary effects, the continuity equation for the excess minority charge carrier density photogenerated in the base of the photocell can be written as follows [13]:

$$D\left(\frac{\partial^2\delta(r,z)}{\partial r^2}+\frac{\partial^2\delta(r,z)}{\partial z^2}+\frac{1}{r}\frac{\partial\delta(r,z)}{\partial r}\right)-\frac{\delta(r,z)}{\tau^*}=-g(z) \quad (1)$$

τ^* is the lifetime of the charge carriers in the base depending on the density of the interface states at the grain boundaries [14].

$$\tau^*=\frac{2\times r\times\exp(-q\times Vd/Kb\times T)}{3\times\sigma\times v\times N_{is}\times(Efn-Efp)} \quad (2)$$

L^* is the diffusion length of charge carriers in the base depending on the density of interface states at the grain boundaries [15].

$$L^*=\sqrt{\tau^*\times D} \quad (3)$$

With D diffusion coefficient, τ^*minority charge carrier lifetime dependent on the interface state of the grain boundaries, $\delta(x)$ minority charge carrier density in the base of the photocell, N_{is} the densities of the interface states at the grain boundaries.

$g(x)$ Represents the rate of generation of the minority charge carrier density in the photocell base, it is written as [11, 12]:

$$g(x)=\sum_{i=1}^{3}n\times a_i\times e^{b_i x} \quad (4)$$

a_i et b_i represent, respectively, the values of the AM1 spectrum ($cm^{-3}.s^{-1}$) and the absorption coefficient of silicon (cm^{-1}).

The following equations represent the boundary conditions of the photocell where Sf is the junction recombination rate, Sb is the backside recombination rate and Sgb is the grain boundary recombination rate [8, 13]:

$$\left.\frac{\partial\delta(r,z,N_{is})}{\partial z}\right|_{z=0}=\frac{Sf}{D}\delta(r,z=0,N_{is}) \quad (5)$$

$$\left.\frac{\partial\delta(r,z,N_{is})}{\partial r}\right|_{r=R}=-\frac{Sgb}{D}\delta(r=R,z,N_{is}) \quad (6)$$

$$\left.\frac{\partial\delta(r,z,N_{is})}{\partial z}\right|_{z=H}=-\frac{Sb}{D}\delta(r,z=H,N_{is}) \quad (7)$$

3. Results and Discussion

Minority charge carrier density in the base

$$\delta_1(r,z,N_{is})=\sum_{i=1}^{3}\sum_{k\geq 0}^{\infty}(A_{i,k}\times r+M_{i,k})\sin(C_k\times z)+K_{i,k} \quad (8)$$

$A_{i,k}$, $M_{i,k}$ et $K_{i,k}$ are coefficients of the solution of the continuity equation for the front side illumination of the photocell.

Figure 2 shows the minority charge carrier lifetime as a function of thickness under different densities of interface states at the grain boundaries.

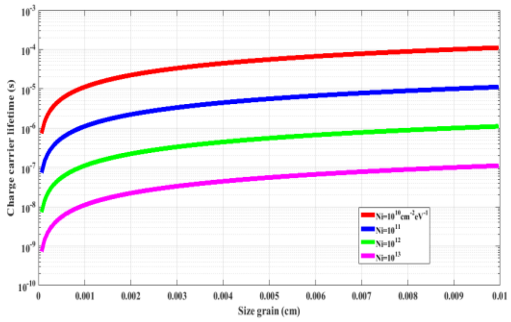

Figure 2: Minority carrier lifetimes as a function of grain size for different densities of interface states at grain boundaries.

The profiles in Figure 2 show the dependence of the minority charge carrier lifetime on the grain size and the density of interface states at the grain boundaries. In this figure, we see that the minority charge carrier lifetime is proportional to the grain size and evolves inversely with the density of interface states at the grain boundaries. For low angle grain boundaries $N_i = 10^{10}$ à 10^{12} $cm^{-2}eV^{-1}$, the charge carrier lifetime is much larger compared to that of high angle grain boundaries $N_i = 10^{13}$ $cm^{-2}eV^{-1}$ and above.

Figure 3 shows the dependence of the minority carrier concentration on the density of interface states at grain boundaries.

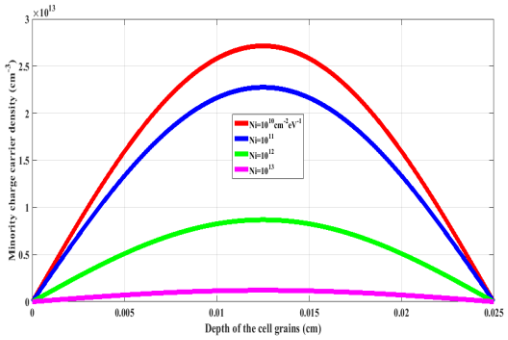

Figure 3: Effect of the density of interface states at grain boundaries on the concentration of minority charge carriers in the solar cell.

The different curves in Figure 3 illustrate minority charge carrier densities that decrease with the density of interface states at the grain boundaries. The explanation that can be drawn from this is that the grain boundaries have a great influence on the minority charge carriers in the base of the cell. This explanation is quite true when we know that, according to [14, 18], the grain boundaries have defects and impurities that contain recombination sites that favour the reduction of charge carriers.

Figure 4 illustrates the dependence of the photocurrent density on the density of interface states at grain boundaries.

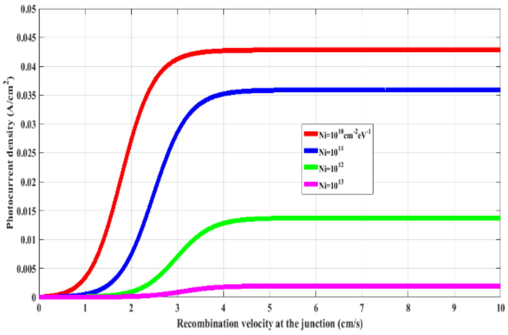

Figure 4: Photocurrent density versus recombination rate at the junction for different densities of interface states at grain boundaries.

For Figure 4, the profiles show the influence of the density of interface states at the grain boundaries on the photocurrent density. Indeed, the understanding that one can have on this explanation is that the current is inversely proportional to the effect of the grain boundary. This is confirmed by [19] who illustrate that, at grain boundaries, charge carriers are under conditions of trapping and recombination which results in a decrease in their lifetime.

Figure 5 shows the photovoltage density as a function of the recombination rate at the junction under different densities of interface states at the grain boundaries.

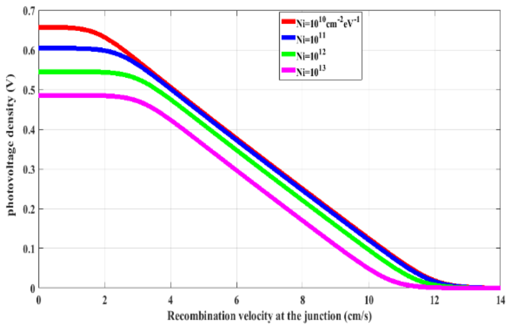

Figure 5: Photovoltage density versus recombination rate at the junction for different densities of interface states at grain boundaries.

We note that, from Figure 5, the photovoltage density is dependent on the recombination rate at the junction and the density of interface states at the grain boundaries. Illumination of the cell from its front side shows that:

- For low recombination speeds (up to 2cm/s), the photovoltage density is maximum and constant. According to [20], this situation defines an open circuit, the carriers are blocked at the junction.
- From 3cm/s onwards, the voltage gradually decreases with increasing recombination rate at the junction up to 12cm/s. However, there is a reduction in carrier storage that accompanies the increase in photocurrent [21].
- The photovoltage is minimal and constant from 13cm/s. In fact, the maximum carrier crosses the junction, we are in a short-circuit situation, the current is maximum.

The increase in the density of interface states at the grain boundaries leads to a decrease in the photovoltage. This shows that the grain boundaries have a large influence on the photovoltage. This explanation reflects the trapping of charge carriers at the grain boundaries, which reduces the storage of charge carriers at the junction.

Conclusion

In this study, we have illustrated the results of the impact of the grain boundaries of the multicylinder polycrystalline solar cell on the minority charge carrier lifetime and electrical parameters. The dependence of the polycrystalline solar cell performance on the density of interface states at the grain boundaries was investigated. This work shows that the grain boundaries have a great influence on the electrical characteristics of the polycrystalline multi-cylinder grain solar cell. The evaluation of the performance of this polycrystalline solar cell and the lifetime of the minority charge carriers also showed that the density of interface states at the joints has a negative influence on the current as well as on the voltage. Simulations revealed that increasing the grain size decreases the effects of the density of interface states at the grain boundaries on carrier lifetime and performance.

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