I-V Characteristic Modeling of in-field Aged Polysilicon Solar Cells

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Abstract: We measured the dark I-V characteristic of polysilicon solar cells. The samples used for this experiment were cell pieces extracted from a photovoltaic panel that has been operating during twelve years under in-field conditions. The measurement has been performed under controlled temperature from 77 K to 300K. The reverse current was important and varies with the voltage.

To explain the behavior of the I-V curve, we proposed a three exponential model justified by conduction mechanisms occurring in these samples. The computation of the model was performed using Maple V. The iterative method that we used gave good fitting results. The parameters (Rs, Rsh, Is and n) of the equivalent circuit that make the theoretical curve fit with the experimental one have been determined from the comparison of theoretical and experimental values and their behavior has been plotted versus the temperature. We propose a conjecture about the grain boundaries role in the saturation current in goal to explain the origin of degradation of the fill factor.

Key Words: Current-voltage characteristic, Polysilicon Solar Cell, In-field Aged.

1 Introduction

I-V characteristic of in-field aged solar cells may give a lot of information about the evolution of the semiconductor material by studying the behavior of the curve. In this purpose we dismantled a PV panel, took out pieces of the cells and soldered ohmic contacts on them and measured their I-V characteristic. We remarked that they lost their fill factor and especially they show a very important reverse current. To try to explain this behavior we modeled the I-V characteristic and computed the current to compare it to the experimental curve. We did this for room temperature and different temperatures computed the current to compare it to the experimental curve. We found that for temperatures from 77 K to 250 K, the reverse current is important and varies versus the forward bias

Diffusion and recombination currents are the commonly expressed as follows:

\[ I_{diff} = I_0 \times e^{\frac{qV}{nkT}} \quad (1) \]

where \( I_0 \) is the saturation current, \( n \) the ideality factor, \( k \) is Boltzmann’s constant and \( T \) the temperature in Kelvin.

Recombination current in the space charge regions (SCR) varies as:

\[ I_{rec} = I_s \times e^{\frac{qV}{nkT}} \quad (2) \]

where \( I_s \) is the saturation current, \( n \) the ideality factor, \( k \) is Boltzmann’s constant and \( T \) the temperature in Kelvin.

2 Modeling

For this mechanism, the ideality factor \( n \) is theoretically equal to 2. However, for our cell this factor is higher than 2, and it is attributed to a conduction mechanism assisted by trap states at active grain boundaries. These states may be due to a precipitation of the impurities during very hot weather.

We propose a model of three diodes with different parameters \( (I_s, n) \) to explain the I-V characteristic of our cells under dark conditions.

3 Proposed model and parameters extraction method

Figure 1 presents an ideal equivalent circuit which includes the three previous conduction mechanisms, associated with a series resistance \( R_s \) and a parallel parasitic resistance \( R_{sh} \). Using this model the I-V characteristic is expressed as follows:

\[ I = I_{d1} e^{-\frac{qV}{nkT}} + I_{d2} e^{-\frac{qV}{nkT}} + I_{d3} e^{-\frac{qV}{nkT}} \]

\[ + I_{s1} e^{-\frac{qV}{nkT}} + I_{s2} e^{-\frac{qV}{nkT}} + I_{s3} e^{-\frac{qV}{nkT}} \]

\[ = \frac{V - R_s I}{R_{sh}} \]

where \( I \) is the current, \( V \) the voltage, \( I_{d(i=1, 2, 3)} \) are saturation currents, \( n \) \( (i=1, 2, 3) \) are the ideality factors, \( q \) is the electronic charge, \( k \) is Boltzmann’s constant and \( T \) the temperature in Kelvin.

The determination of the parameters is done with the following sequences:

**First phase:** only the forward bias curve is considered with an infinite shunt resistance \( R_{sh} \). From equation (3) and the assumed infinite shunt resistance, it is seen that the solar cell parameter extraction problem reduces to the determination of seven parameters \( (I_{d1}, I_{d2}, I_{d3}, n_1, n_2, n_3, R_s) \).
from the forward bias of the dark I-V characteristics, i.e. three saturation currents, three ideality factors and the series resistance.

Second phase: the reverse I-V curve is simulated; the parasitic $R_{sh}$ has a great influence on it. Then, only this parameter is considered, the other parameters are those determined in the first phase.

4 Modeling the dark I-V characteristic

At room temperature, the proposed model gives a good fitting with the experimental result.

Figure 2 shows the theoretical and experimental curves. From Maple V simulation and after fitting, we have extracted the following parameters:

$I_{S1} = 1.71 \times 10^{-7} \; A$; $I_{S2} = 3.9 \times 10^{-11} \; A$; $I_{S3} = 1.27 \times 10^{-6} \; A$; $n_1 = 1$; $n_2 = 2$; $n_3 = 3.1$; $R_S = 2.06 \; \Omega$

The three saturation currents do not vary in the same way and temperature. $n_1$, $n_2$ and $n_3$ go respectively from 1, 2 and 3.1 at 300 K to 3.9, 6.15 and 6.7 at 77 K.

The three saturation currents do not vary in the same way with the temperature. If the current due to the conduction and the current due to the generation-recombination varies exponentially with the temperature (Fig. 8), the third current due to the grain boundary states, which we added, varies exponentially with $1/T$ (Fig. 9). This latest saturation current component dominates the two others at lower temperature. The conduction process assisted by trap states at grain boundaries may be the cause of premature degradation of the fill factor of in-field aged solar cells.

The shunt resistance varies exponentially with temperature though the series resistance decreases versus temperature. Such behaviors have been also observed by Kaminski [4] and Veissid [5].

6 Summary and conclusion

We tried to understand the physics reasons of the deterioration of the I-V fill factor of the characteristic of in-field aged solar cells. We proposed a model for the equivalent circuit of the cell with three diodes, one for the conduction current, one for the generation-recombination current and one for the parasitic current due to trap states effect assisted by extended defects, especially active grain boundaries.

We believe that the working of the cells during thirteen years under the sun in very hot weather causes a precipitation of impurities. These impurities may be responsible of a parasitic leakage visible under reverse bias [6].

Our model has been applied for various temperatures between 77 and 250 K. The ideality factors vary linearly with temperature (Fig. 7). They increase linearly with decreasing temperature. $n_1$, $n_2$ and $n_3$ go respectively from 1, 2 and 3.1 at 300 K to 3.9, 6.15 and 6.7 at 77 K.

The measured I-V characteristics of our polysilicon solar cell were plotted. For 300K, the shunt resistance is $R_{sh0}=10054 \; \Omega$. For temperature dependent measurements, the cell was put inside a liquid helium cryostat regulated from 4K to 400K.

For temperatures between 180 and 300 K the value of the shunt resistance behavior is as low as it is used to be; but at temperatures lower than 180 K it takes very high values due to an unknown phenomenon.

On the other hand, the variation of the pre-exponential factor $R_{sh0}$ of the shunt resistance, which may be attributed to a leakage current at grain boundaries stimulated by the voltage, stands between 12500 and 16500 $\Omega$. This leakage may be due to segregation and precipitation of impurities at the grain boundaries. Figure 6 shows variation of $R_{sh0}$ versus temperature. These variations may be not significant.

References