Numerical Two Dimensional Modeling of Silicon Solar cells with Experiment Validation

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SUMMARY

A two dimensional numerical model for silicon solar cells has been developed in COMSOL. This model calculates the influence of emitter doping profile, sheet resistance, and recombination on the performance of the solar cell in two dimensions. The solar cell model has an n^+ p p^+ structure with a measured doping profile in the emitter and uniformly doped back surface field. The surface recombination velocity at the front surface is calculated based on the surface doping density. The carrier flow pattern in the solar cell was analyzed by solving the diffusion equations using appropriate boundary conditions. The numerical model was developed in COMSOL by solving the Poisson equation, the current density equation and the continuity equation in each region. An important design parameter of conventional Si solar cells is the emitter region and determining its influence on front contact spacing. This model can also be used for optimizing the front contact design. The model uses finite element analysis for these calculations. Solar cells have been fabricated with various emitter doping profiles and are characterized. Experimental I-V characteristics and IQE response values are compared with simulation results.

I. INTRODUCTION

Since 1D models assume vertical flow of carriers they over-estimate the current flow in the emitter and hence ohmic losses. A proper numerical treatment will result in calculating the optimal distance of the current flow in the emitters. Several commercial two dimensional numerical models exist and most of them are built in SENTAURUS device software. COMSOL is numerical modeling software that works on the principles of finite element analysis. It is a Multiphysics program that permits the simultaneous solution of many coupled physical problems. A two dimensional numerical model was developed in COMSOL for the analysis of silicon solar cells mainly in the emitter region. This model can be used as a low-cost alternative to the existing 2D models. Some of the important features of the 2D model are described in the next section.

II. 2D SOLAR CELL MODEL

In this work, a two dimensional solar cell model was developed with n^+ emitter on a p type base region with p^+ (Al) back surface field. An arbitrary doping profile can be used in the emitter region and the base is uniformly doped. Constant bulk electron and hole lifetimes are used in this model. The modeling was performed using COMSOL's Multiphysics numerical simulation package. The comparison of the model simulation results with PC1D was presented elsewhere [1]. The comparison of 2D model simulation results with experimental results is presented in this paper.

II a. Numerical Model Parameters

Solar cell modeling includes several parameters that influence the performance of the solar cell. Figure 1 shows the solar cell structure "unit cell" used for modeling. The structure has a uniformly doped p-type substrate and a shallow emitter. The emitter junction depth varies with the doping profile. The thickness of the substrate is taken as 200µm. The emitter is n-type with arbitrary doping profile. The width of the unit cell is taken as 1000µm as it is the half spacing width between two front silver fingers. Five percent of the front surface is covered by silver contact. The bottom of the base region was completely covered with an Aluminum rear contact. The back aluminum also acts as back surface field (BSF). Bulk carrier life time is measured to be 400µs.The light source was taken to be on the front surface so that the carrier generation starts from the front surface and reduces as it goes deep into the solar cell. A measured reflectivity curve of the cell is used in calculating the carrier generation rate. The surface recombination velocity (SRV) under the metal contacts is taken to be $1x10^6$ cm/s and the SRV varies linearly with surface doping density

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as $S = 10^{-16}N_D$ for $N_D > 10^{18}cm^{-3}$ for passivated surface [2].

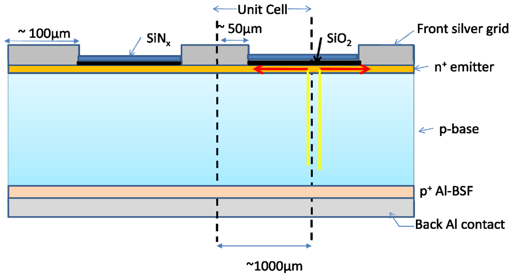

Figure 1 Solar cell structure with front and rear contacts shown and with p^+ BSF

Fermi-Dirac statistics are used in the heavily doped emitter region with band gap narrowing data developed by Schenk [3]. Heavy doping leads to degeneracy in the emitter region and hence to account for this, degeneracy factor is included to calculate the electron and hole concentrations [4, 5]. Auger recombination is considered in the heavily doped emitter region and in BSF region. Intrinsic carrier concentration of $1x10^{10}cm^{-3}$ is used [6]. The solar cell was forward biased with an applied voltage on the front contact relative to the back contact. The current density, continuity diffusion equations and the Poisson's equation were solved using the boundary conditions in the emitter and base regions. The trajectory of electrons in the base region is simulated using the model and 3D surface plot of electron concentration in the cell is shown in Figure 2.

III. EXPERIMENTAL VALIDATION

A series of experiments were conducted to compare the developed 2D model with real time data. Solar cells were fabricated in the Suniva's R&D facility with p-type substrates doped to 1-3Ω-cm. The bulk lifetimes were measured to be ~400µs. The emitters were doped with Phosphorus with various doping densities. After doping, they were nitride coated with SiN_x and screen printed with silver grid on the front and Aluminum on the back. After firing the metal, Al is alloyed with silicon and forms back surface field (BSF). Doping profiles were measured for phosphorus in the front emitter and aluminum in the BSF region. I-V and IQE characteristics were measured on these cells. All the input parameters are given to the model and the experimental results are compared to the simulated results as shown in Figures 3 and 4. The model doesn't include contact resistance effects and hence the fill factor is higher compared to the measured values.

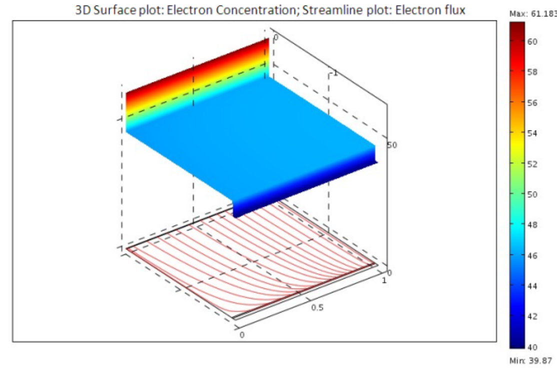

Figure 2 3D plot of electron concentration and its trajectory in the base towards the emitter region

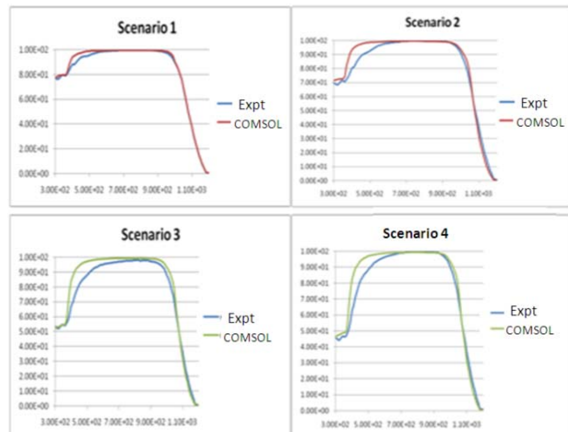

Figure 2 Comparison of simulated IQE curves with measured results for different scenarios

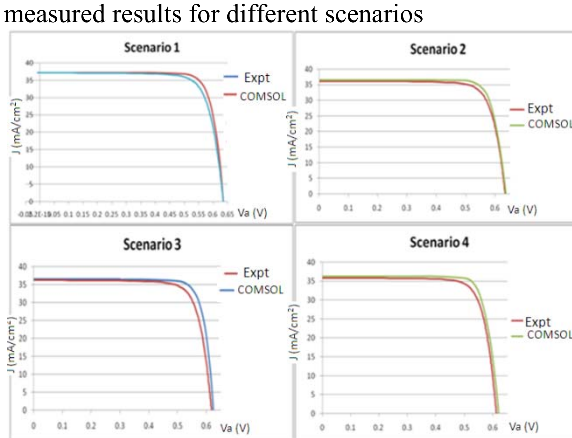

Figure 3 Comparison of simulated I-V curves with measured results for different scenarios

IV. REFERENCES

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