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Two dimensional device simulation and performance optimization of n-type silicon solar cell structure using PC2D

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ABSTRACT

In this paper, we analyze the impact of various parameters on the performances of the n-type monocrystalline silicon solar cell experimented by Fraunhofer Institute for Solar Energy Systems (ISE) in Germany. We studied, especially the influence of the base parameters (lifetime, resistivity and thickness), the emitter sheet resistance and the back surface field (BSF) sheet resistance, on the solar cell performances.

To optimize this cell we have used PC2D which is a solar cell device simulator that models two-dimensional effects entirely within a Microsoft Excel spreadsheet. With an Al_2O_3/SiN_x front side boron emitter passivation, the metallization parameters were optimized by the authors getting efficiency of 19.60%. If all the parameters have ideal values our optimization provided an efficiency of 20.05% for homogeneous emitter with sheet resistance of 75 Ω/□. Furthermore, the study of the emitter led to a new structure developed recently: the selective emitter of n-type solar cell achieving efficiency of 20.20% with sheet resistance of 50 Ω/□ under the contacts and 100 Ω/□, between contacts.

1. Introduction

The first silicon solar cells were made on n-type substrates in 1950s. This technology changed to p-type substrates because of their high resistance to space radiation, at a time when the only application for those cells was for space (Zhao et al., 2002).

Up to a certain period, all commercialized silicon solar cells were realized on p-type silicon substrate because the technology of their production was easily industrialized and accessible. The photovoltaic industry of silicon was therefore developed around this idea and terrestrial market is still mainly supplied today by cells in p-type silicon (Wang and Wang, 2014). Another reason of the choice of p-type crystalline silicon is that the electrons mobility (minority carriers) is higher about three times than the holes, so they have a big diffusion length, and then it is easy to collect them (Sze and Ng, 2007).

Nevertheless, in equivalent technology, the best results of efficiency are obtained with n-type crystalline silicon solar cells (20–25%) (Green et al., 2015). For example, Benick et al. (2008) obtained a maximum efficiency of 23.2% on 4 cm^2 surface cells.

The main cause of this is the presence of very recombinant defects in the p-type crystalline silicon, particularly boron-oxygen pairs which are generated under illumination and are responsible of the loss of cells efficiency during the first months of operation (Light-induced degradation: LID) (Schmidt et al., 2003; Bothe et al., 2005). Cells with n-type crystalline silicon doped with phosphorus are not affected to this type of defects and are much more stable over time (Lim et al., 2011). Furthermore, the n-type wafers may offer greater immunity to the effects of metal contaminants like iron, molybdenum, titanium and others (Macdonald and Geerligs, 2004), so these cells have a high lifetime exceeding 1 ms (Zhao et al., 2002; Cuevas et al., 2002).

In this work, we would optimize the following layer parameters: base, emitter and BSF for n-type solar cells to improve their efficiency using PC2D (Basore and Cabanas-Holmen, 2011).

2. Simulated devices

The design used is a two-busbars p^+nn^+ full square monocrystalline silicon cells of real surface 139.3 cm^2 (125 mm × 125 mm), homogenously boron doped front side emitter with a sheet resistance of 90 Ω/□ corresponding to a surface doping concentration of 6×10^{19} cm^{-3} and a depth of about 0.25 μm calculated with PC1D (Clugston and Basore, 1997). The back side was doped by a

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phosphorous gaussian profile of 30 Ω/□ corresponding to a surface doping concentration of 3×10^{19} cm^{-3} and a depth of 2 μm then contacted with evaporated aluminum on the whole cell area (Kalio et al., 2011; Richter et al., 2010).

The front surface was textured with alkaline (KOH) in the purpose to have a surface pyramid structure with angle of 54.74° and depth of 3 μm, passivated with aluminum oxide (Al_2O_3) then covered with silicon nitride (SiN_x) antireflective coating layer (Fig. 1) (Kalio et al., 2011; Richter et al., 2010).

Using inkjet and aerosol jet printing with consequent silver electroplating, the metallization was optimized by Kalio et al. (2011) (Fraunhofer ISE) giving a contact resistance values of 3.8 Ω cm^2, series resistance of 0.64 Ω cm^2 (verified by calculation) and shunt resistance of 65 kΩ cm^2.

The most optical parameters for all simulated solar cells are taken from examples of Basore and Cabanas-Holmen (2014).

3. Simulation program

The simulation is done with PC2D which is relatively a new solar device simulator (2011) that models two-dimensional effects of solar cells with the companionship of PC1D (Basore and Cabanas-Holmen, 2011).

The region simulated by PC2D is the smallest elementary part, representative of the entire cell area of 1 cm^2. The solution region is defined by X which is the width measured from the center of the contact to the midpoint situated between the center of two successive contacts, and Y which is the thickness of the cell. This region is divided into a grid of 20 × 20 identical rectangular elements bordered in two perpendicular directions by a mesh of 21 × 21 nodes (Fig. 2) in which the continuity equations and minority carriers current (n, p) are solved by the method of finite elements (Basore and Cabanas-Holmen, 2011):

$$dn/dt = G_n - R_n + div\boldsymbol{J_n}/q$$

$$dp/dt = G_p - R_p - div\boldsymbol{J_p}/q$$

$$\boldsymbol{J_n} = q\left(n\mu_n\boldsymbol{E} + D_n\boldsymbol{grad}n\right)$$

$$\boldsymbol{J_p} = q\left(p\mu_p\boldsymbol{E} - D_p\boldsymbol{grad}p\right)$$

The vectors $\boldsymbol{J_n}$,$\boldsymbol{J_p}$ (in bold type) are carrier currents, G_n and G_p: rates of carrier generation, R_n and R_p: rates of carrier recombination, μ_n and μ_p: carrier mobilities, D_n and D_p: constants carrier diffusion (n for electrons and p for holes respectively), the vector $\boldsymbol{E}$ is the whole electric field across the structure and q, the electronic charge.

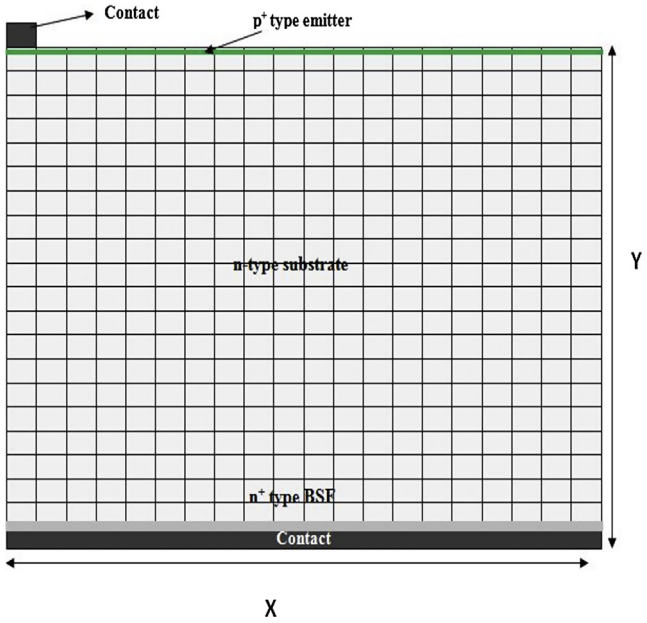

Fig. 2. Mesh of the simulated region.

The boundary conditions at the top and bottom surfaces represent the complex physics occurring in the very thin layers adjacent to each of these surfaces. The boundary conditions at the left and right side boundaries of the solution region can be either reflecting or repeating, according to the user's specification (Basore and Cabanas-Holmen, 2011).

The user defines the solar cell that he wishes to model in the "Device" and "Recombination" sheets with it solution region, typically selected to extend from the middle of a gridline to the midpoint between gridlines. In the "Device" sheet, we enter the structural, electrical and optical parameters. In "Recombination" sheet, we integrate recombination density currents J_{01} in doped emitter and at metal contacted surfaces of the cell, and the recombination density current J_{02} in the space charge region. J_{01} and J_{02} are determined by PC1D (Cabanas-holmen and Basore, 2012).

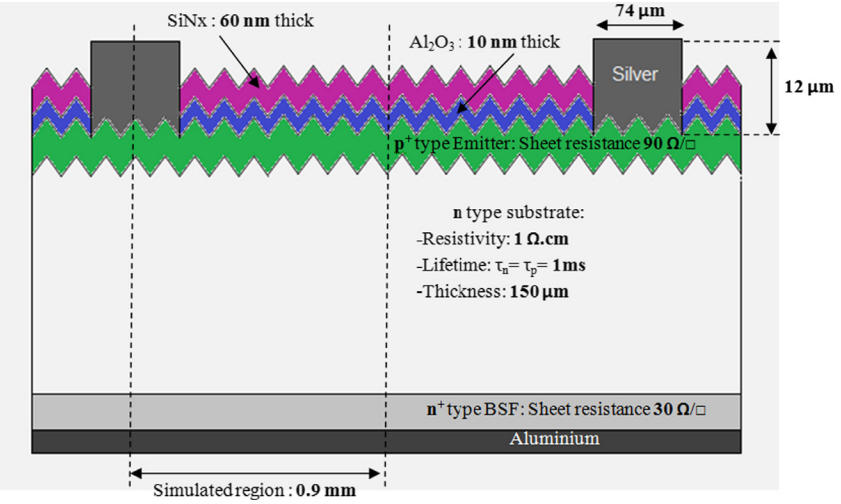

Fig. 1. Parameters used of simulated solar cells.