Numerical Simulation of One-Dimensional Solar Cell Model

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ABSTRACT: Solar energy is becoming one of the primary sources energy in the world which converts energy from the Sun into electrical energy and thermal. The renewable energy source can gradually replace fossil fuels for domestic, commercial, or industrial use due to its abundance, versatility, and environmental-friendly. The purpose of this project is to provide a better understanding of the operation of solar cell by using one-dimensional (1D) solar cell model which accounts for the charge transport via the drift-diffusion, the electric potential by Poisson's equation and the ion generation and recombination rate. The Finite Difference Method is used to solve the model of Monocrystalline Silicon (Mono-Si) numerically through implicit Ordinary Differential Equation (ODE) solver 'ode15s' in MATLAB. Then, the performance of the Mono-Si solar cell is analysed. The numerical analysis provides a deep understanding on the dynamic operation of Mono-Si solar cell. It is found that the thickness of the cell affects the performance of solar cell.

Keywords: 1D Drift-diffusion model; Monocrystalline Silicon solar cell, Finite Difference Method

1. INTRODUCTION

The Sun that has been burning over 4 billion years supplies sunlight to the Earth, converting into electrical energy through photovoltaic cells (PV). Solar radiation is a radiant energy released by the sun due to its nuclear fusion reactions [1]. According to Askari et al. [2], this renewable energy source can replace the demand of electricity that community get from 650 barrels of oil per year.

PV is a fast-growing market. Silicon wafer-based PV technology accounted for about 95% of the total production in 2019 where 66% of it is Mono-Si technology [3]. The market has a steady improvement of conversion efficiency and a gradual reduction of the cost of modules and systems which making a significant contribution to the global energy system.

The state of art of solar cell model is greatly improved with its efficiency. However, the complexity of the transport equations is the concerning part in the process of analysing the derivation of equations that high numerical competency is required.

The purpose of this paper is to establish the solar cell modelling in blend phase through numerical analysis and analyse the performance of Mono-Si solar cell material for different thickness.

2. METHODOLOGY

2.1 MECHANISM OF 1-D SOLAR CELL

A schematic diagram of solar cell is shown in Figure 1. Mainly, light absorption occurs in blend phase where electron gain and lose energy is described by the bulk generation and recombination of electron-holes pair. Due to charge separation at the interphase, it allows only holes pass through into donor phase while only electrons into acceptor phase.

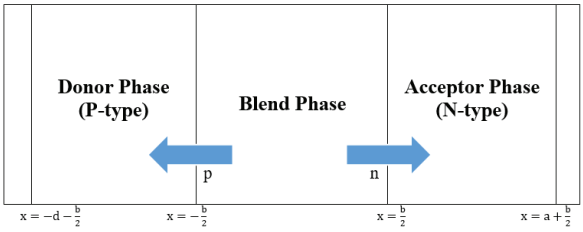

Figure 1: Schematic diagram of solar cell

2.2 SEMICONDUCTOR MODEL EQUATIONS

In this research, we assumed that the thickness of donor phase and acceptor phase are significantly small. Thus, the thickness across blend phase in Figure 1, at $x = -\frac{b}{2}$ is modelled as $x = 0$ while the thickness $x = \frac{b}{2}$ is represented as $x = L$. Therefore, the mathematical model of solar cell in blend phase is written as following:

Poisson's Equation

$$\frac{\partial^2 \varphi}{\partial x^2} = \frac{\rho}{\varepsilon} = \frac{q}{\varepsilon}(p - n - N_A + N_D) \quad (1)$$

Drift-Diffusion Transport Equations (current density)

$$J^n = qD_n\left(\frac{\partial n}{\partial x} - \frac{qn}{kT}\frac{\partial \varphi}{\partial x}\right) \quad (2)$$

$$J^p = qD_p\left(\frac{\partial p}{\partial x} + \frac{qp}{kT}\frac{\partial \varphi}{\partial x}\right) \quad (3)$$

Continuity Equation

$$\frac{\partial n}{\partial t} - \frac{1}{q}\frac{\partial J^n}{\partial x} = G - R \quad (4)$$

$$\frac{\partial p}{\partial t} - \frac{1}{q}\frac{\partial J^p}{\partial x} = G - R \quad (5)$$

where p, n are the density of holes and electrons, respectively, J^i is the current density of ions ($i = p, n$), φ is the electric potential, G is the generation rate and R is the recombination rate. Meanwhile, q is the charge, ε is the permittivity, D_i is the ion diffusivity, k is the universal gas constant and T is the temperature.

The boundary conditions of (1) – (5) are as follows:

At $x = 0$, $p_x = n = 0$ (6)

$\varphi = V_0$ (7)

At $x = L$, $n_x = p = 0$ (8)

$\varphi = 0$ (9)

Initially the charge densities of both charge carriers:

$$p(x, 0) = n(x, 0) = \pi_0 \quad (10)$$

where π_0 is the charge densities at the equilibrium state.

2.3 NUMERICAL SIMULATION

By discretizing the spatial variable of (1) – (5) using finite difference approximation with respective boundary condition (6) – (9), the partial differential equations are converted into a set of ODEs. The ODEs are then being solved by using implicit ODE solver 'ode15s' in MATLAB. The efficiency of the cell is then calculated by substituting the current density of charge carriers into the solar cell efficiency formula. Table 1 shows the value of parameters for Mono-Si material that are substituted into the numerical simulation.

Table 1 Parameters of Mono-Si material as in [4]

Parameter	Value (unit)
Permittivity, ε	1.045×10^{-10}cm^{2}V^{-1}s^{-1}
Electron diffusion coefficient, D_n	3.489×10^{-3}m^{2}s^{-1}
Hole diffusion coefficient, D_p	1.240×10^{-3}m^{2}s^{-1}
Thickness, L	0.25µm
Temperature, T	300K
Initial charge density, π_0	7.9×10^{23}m^{-3}
Charge, q	1.602×10^{-19}C
Universal gas constant, k	1.38×10^{-23}J/K

3. RESULTS AND DISCUSSION

The results from the model compare reasonably well to experimental data given by Jamie et al. [5] as shown in Figure 2. Although, we remark that the large difference at the edges of the interphase of the simulation in comparison to the experimental may be because we solved the model in blend phase only where we neglect the charge transport at the donor and acceptor phases. Charge separation occurs at $x = 1$ where electrons diffuse into the acceptor region justified by the large jump in electron affinity between the blend phase and acceptor phase. This approximation can be further improved by considering the solution of the model for all phases. Meanwhile, the hole density against the cell thickness is shown in Figure 3. At $x = 0$, the active layer at the interphase allows the transport of holes (and block the other) to across into donor phase. It is also shown that the bulk electron-holes carriers' densities are significantly concentrated in the blend phase as reacted upon the light absorption by the Mono-Si (refer Figure 2 and 3).

The comparison of efficiency for different thickness is shown in Figure 4. It is found that 25.5% efficiency on the Mono-Si solar cell of thickness $0.25\mu m$ which totally achieves a good performance. However, the efficiency reduces to 16.2% with the decrease of thickness of solar cell at $0.15\mu m$.

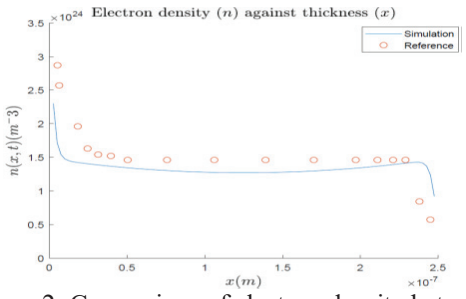

Figure 2: Comparison of electron density between simulation and experimental data [5]

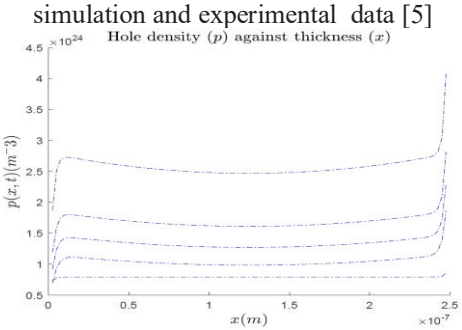

Figure 3: Hole density against thickness

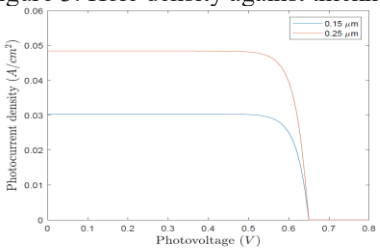

Figure 4: J-V characteristic curve of silicon solar cell with different thickness

4. CONCLUSION

Drift-diffusion model of one-dimensional solar cell in blend phase is presented and is solved using Method of Lines technique. The charge densities of holes and electrodes behavior across the thickness have been shown. The smaller the thickness of cell the lower the cell efficiency. It can be concluded that, this model would be useful for a guideline of the thickness of cell that predicts the Mono-Si solar cell performance with incorporation of the current density equation.

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