Simulation of the Optimized Performance of Thin-Film Silicon Solar Cell with Nano-holes Surface Structures

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Abstract- **The optical generation rate and surface recombination velocity (SRV) increasing with the created nano-holes depth, width, and number on the emitter layer of a thin-film silicon solar cell are studied. The trade-off between the optical generation rate and surface recombination velocity was exhibit in short-circuit current density (J_{sc}), Open-circuit voltage (V_{oc}), and conversion efficiency (η) using a two-step simulation. The simulated results indicated that a thin-film solar cell with a proper nano-holes structure on the emitter layer can be achieved a much high J_{sc} and η performances.**

I. INTRODUCTION

In order to reduce the high reflectivity of silicon surface, the antireflection coating (ARC) [1] and subwavelength surface structure [2] were widely used in photovoltaic devices. Some simulated methods were used to examine the photovoltaic performance enhancement with a subwavelength surface structure. Finite-Difference Time-Domain (FDTD) [3], rigorous coupled-wave analysis (RCWA) [4] and finite element method (FEM) [5] have widely used in photovoltaic device simulations.

In this study, the commercial software APSYS, which is based on FEM method, is used to simulated the optical generation rate and surface recombination velocity (SRV) [6] created on the emitter layer by the nano-holes structure. The trade-off between the optical generation rate and the SRV to obtain a high efficiency thin-film Si solar cell is simulated and discussed.

II. SIMULATION SETUP

Two step simulations of 2D model are proposed in this study. The simulation flow chart is shown in Fig. 1. The SRV value of a fabricated bare-plane type Si solar cell was firstly obtained using different SRV values on APSYS-software to simulate and find the one which the SRV value that meet with the result of short-circuit current density (J_{sc}) obtaining from photovoltaic I-V measurement under one-sun AM 1.5G solar simulation. The obtained SRV value will be used in the second step for furtherly simulation. The simulation model of bare-plane type Si solar cell, in Y-direction, is consisted of a 0.87 μm-thick p^+-Si emitter layer, a 5.0 μm-thick n^--Si base layer, a 675 μm-thick n^+-Si substrate, and front/back-side electrodes. In X-direction, however, the front contact electrode width is 27 μm and the illuminated area between two electrodes is 590 μm.

In secondary step, the nano-holes structure is applied on the emitter layer with various depth, width and number for simulations. The simulation sequence in this step is the variation of the hole-depths first, then the hole-widths, and the hole-number finally. It note that the hole number of 3, the hole width of 0.2 μm, and the electrode width of 0.5 μm were fixed first for beginning simulation. The obtained optimized result from the former simulation will give the parameter of the latter simulation. Therefore, the optimized performance of a thin-film Si solar cell with nano-holes surface structures was achieved.

III. RESULTS AND DISCUSSION

The firs-step simulation results are listed in Table I. The SRV of a fabricated bare-plane type Si solar cell obtained by simulation was 1250 m/s, which using the SRV values to simulate J_{sc} and to obtain a simulated J_{sc} value (15.31 mA/cm^2) just equal to the J_{sc} (15.31 mA/cm^2) obtained from photovoltaic I-V measurement under one-sun AM 1.5G solar simulation. The difference in open-circuit voltage (V_{oc}) and Conversion efficiency (η) between the simulation and the experiment data was attributed to the ideal case of the series resistance (R_s = 0) and the shunt resistance (R_{sh} =∞) used for the simulation.

The photovoltaic I-V simulated curves of the solar cell with various hole depth based on the SRV of 1250 m/s are shown in Fig. 2. The J_{sc}, V_{oc}, and η are also summarized in Table II. The optical generation rate and SRV as a function of the depth of nano-hole is presented in Fig. 3. The observed point of the optical generation simulation is also shown in the inset of Fig. 3. The optical generation rate and SRV are increase with the depth of the hole. The simulated photovoltaic I-V results indicate that a 0.2 μm hole depth is an optimal hole depth due to obtaining the highest J_{sc} and η.

If holding the hole depth of 0.2 μm and SRV of 1250 m/s, the simulated results of J_{sc}, V_{oc}, and η as a function the hole width (d) are listed in Table III. The optimal d is 0.15 μm due to obtaining the highest J_{sc} and η. Furthermore, holding the hole depth of 0.2 μm, d of 0.15 μm and SRV of 1250 m/s, the simulated results of J_{sc}, V_{oc}, and η as a function the hole number are presented in Table IV. The optimal hole number is

9 because of obtaining the highest J_{sc} of 19.07 mA/cm^2 and η of 9.42%.

IV. CONCLUSION

In this study, the optimized performances of a thin-film Si solar cell with nano-holes surface structures were simulated. The optical generation rate and SRV of the emitter layer depending on the nano-holes structure with the variation of the hole depth, hole width, and holes number were demonstrated. The highest efficiency reach to 9.42% was obtained in this simulation, compare to the bare-plane type Si solar cell of 9.05%.

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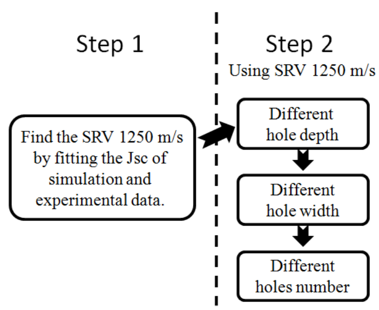

Fig. 1 The diagram of two-step simulation flow chart.

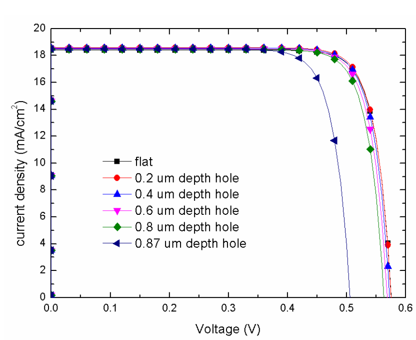

Fig. 2 The simulated photovoltaic J–V curves as a function of the hole depth based on the SRV of 1250 m/s.

Table I

The J_{sc} value obtained by simulation under a specific SRV that equal to the J_{sc} (15.31 mA/cm^2) obtained from photovoltaic I-V measurement. The SRV of a fabricated bare-plane type Si solar cell was 1250 m/s obtained from the first simulation.

	Experiment	Simulation
J_{sc} (mA/cm^2)	15.31	15.31
V_{oc} (V)	0.532	0.581
η (%)	5.64	7.55

Table II

The simulated photovoltaic performance as a function of the hole depth based on the SRV of 1250 m/s.

Nano-holes depth (μm)	J_{sc} (mA/cm^2)	V_{oc} (mV)	η (%)
0	18.42	575.94	9.05
0.2	18.58	575.69	9.12
0.4	18.56	573.06	9.06
0.6	18.50	569.22	8.96
0.8	18.47	563.17	8.84
0.87	18.50	505.65	7.80

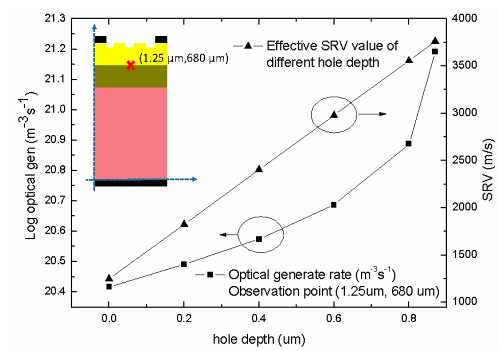

Fig. 3 The simulated optical generate rate and SRV as a function of the hole depth based on the SRV of 1250 m/s.

Table III

The simulated photovoltaic performance as a function of the hole width (d) based on the SRV of 1250 m/s and the hole depth of 0.2 μm.

Nano-holes width (μm)	J_{sc} (mA/cm^2)	V_{oc} (mV)	η (%)
0.05	18.46	572.17	8.99
0.075	18.56	573.23	9.06
0.1	19.00	574.52	9.31
0.15	19.01	575.57	9.33
0.2	18.58	575.69	9.12
0.3	18.33	576.27	9.01
0.4	17.68	575.86	8.69
0.5	17.64	576.18	8.67

Table IV

The simulated photovoltaic performance as a function of the hole number based on the SRV of 1250 m/s , hole depth of 0.2 μm, and hole width of 0.15μm

Nano-holes number	J_{sc} (mA/cm^2)	V_{oc} (mV)	η (%)
3	19.01	575.57	9.33
4	19.03	576.69	9.36
5	19.03	577.49	9.37
6	19.06	578.08	9.40
7	19.06	578.53	9.41
8	19.06	578.89	9.41
9	19.07	579.17	9.42
10	19.02	579.14	9.40