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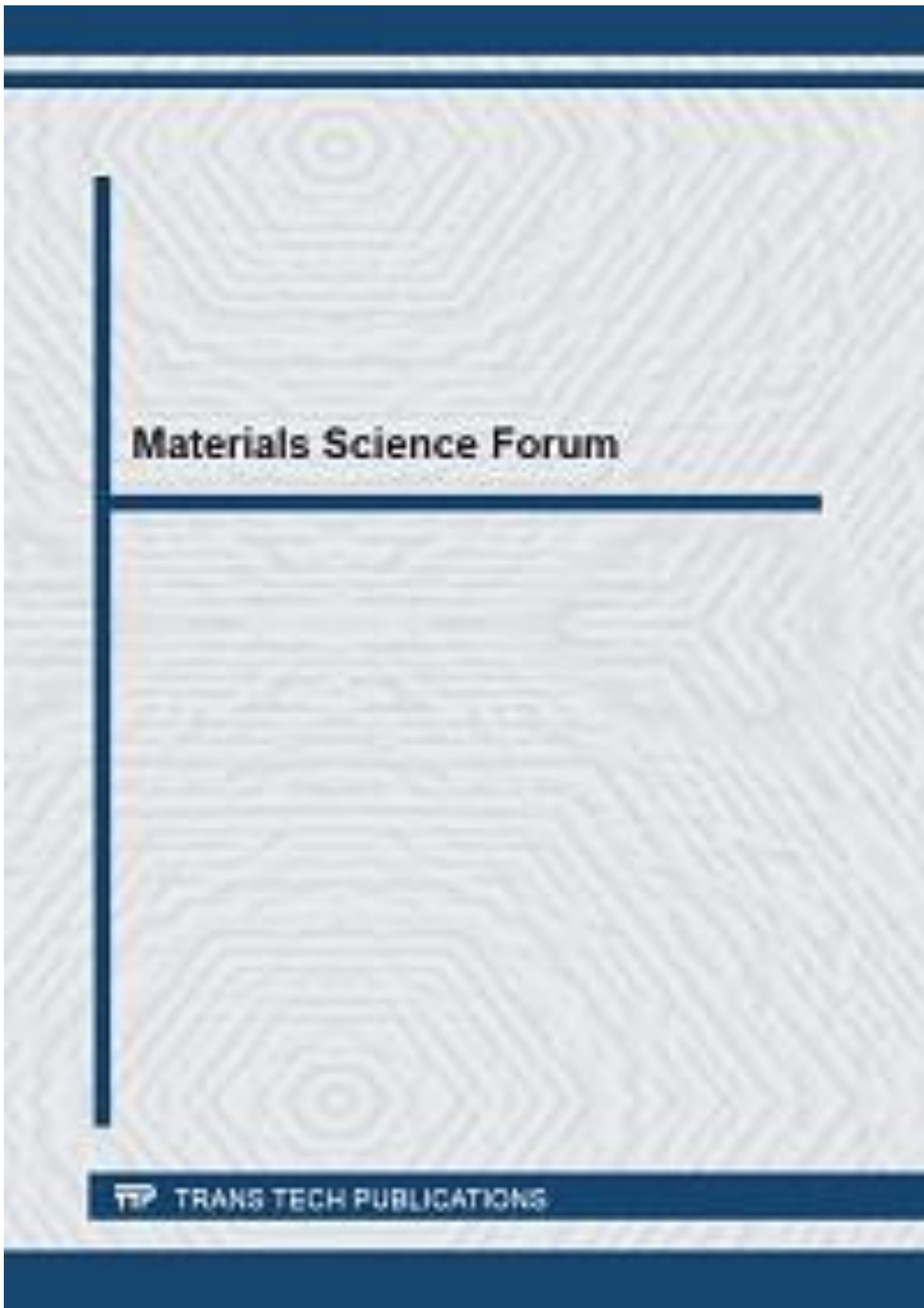
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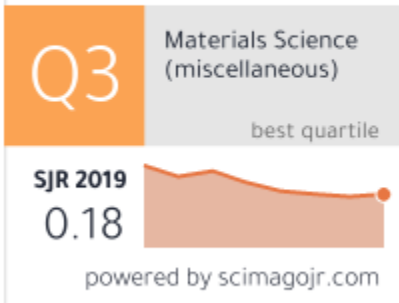|		
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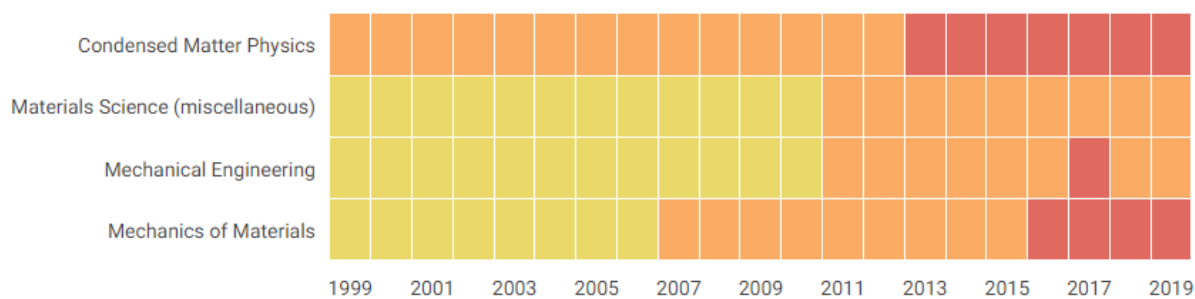
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Band Gap Optimization of Thin Film a-Si:H Bifacial Solar Cells (BFSCs) Using AFORS-HET

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Keywords: AFORS-HET, thin film, BFSCs, simulation, maximum efficiency.

Abstract. Using well-practiced AFORS-HET software, thin film a-Si:H Bifacial Solar Cells (BFSCs) has been investigated and simulated. This study aims to simulate performances of a-Si:H BFSCs with structure of Glass/TCO/(n)a-Si:H/(i)a-Si:H/(p)a-Si:H/TCO/Glass. The results show that the optimized band gap for each layers are 2.0 eV (n-type), 1.7 eV (i-type) and 2.0 eV (p-type), respectively. The final simulation shows that there are significantly increased of V_{OC}, J_{SC}, *FF,* and *Eff* for both side of a-Si:H BFSCs. Finally, the maximum efficiency obtained is 7.79% for the front side and 5.68% for the rear side, respectively.

Introduction

Solar energy is one of the largest energy sources in the world that has not been used optimally. Many efforts have been carried out to convert solar energy into electricity using thin film solar cells to meet the needs of the world energy crisis. The ability of thin film solar cells (a-Si, CdTe, CIGS) as a device capable of converting solar energy into electrical energy commercially should be able to compete with conventional solar cells of crystalline silicon (c-Si). However, thin film solar cells conversion efficiency is still below c-Si 26.7%, there are 13.6% (a-Si), CIGS (22.3%) and CdTe (22.1%) [1]. There are several advantages of thin film based solar cells, including the fabrication costs are relatively cheap by processing at low temperatures, the use of raw materials relatively small, deposition on different substrates (rigid, flexible, lightweight), as well as innovation in structural engineering can be done to improve efficiency [2].

Amorphous silicon (a-Si) has a property related to their short-range (amorphous) order structure and the presence of loose bonds (dangling bonds, DB) which affect optoelectronic property and the length of diffusion of the charge carriers that could influence the conversion efficiency of a-Si. One of the methods that can resolve this limitation is hydrogen passivation which produces hydrogenated amorphous silicon (a-Si:H), but this process causes the degradation of transport properties when exposed to continuous light known as the Staebler-Wronski effect (SWE) due to the presence of the H atom in the bond. During illumination, the increase of the DB density of states that occurs by non-radiative recombination between the electron and the photo-excitation hole (photoexcited) on the weak Si-Si bond that connects with the bond SiHHSi, as well as other defects related to the random arrangement of Si atoms [3], [4].

The concept of bifacial solar cells (BFSCs) is based on the ability of both surfaces to produce electricity. The use of BFSCs with the application of thin films based a-Si:H is carried out through application to building integrated PV (BIPV) with conversion efficiency of 7% for BIPV application with a structure (p)a-Si:H(15nm)/(i)a-Si:H(200nm)/(n)a-Si:H(35nm) [5]. In reality, the involvement of a-Si:H BFSCs can compete with other products, especially with other thin film technologies, so that efforts are needed to improve its efficiency. Optimization of the thickness of bifacial homojunction (HJ) and heterojunction with intrinsic layer (HIT) solar cells with structure a-

Si:H(n)/a-Si:H(i)/c-Si(p) was investigated in detail by computer simulation using the AFORS-HET software with an efficiency of 27.02% [6]. Numerical simulation is used to assist in illustrating for development of thin film solar cells, and we used AFORS-HET (**A**utomat **FOR S**imulation of **Het**erojunction) software developed by Helmholtz-Zentrum Berlin (HZB). AFORS-HET is a computer program that was developed to simulate processes related to charge carrier density, recombination rate, electron and hole flow process, band structure, electric field, and current density, etc. The mathematical model developed in this software is based on solving 1D Poisson's and continuity equations using Shockley-Read-Hall recombination statistics for all layers of solar cells [7].

Performance analysis of a-Si:H BFSCs with structure Glass/TCO/a-Si:H(n)/a-Si:H(i)/a-Si:H(p)/TCO/Glass was investigated via extracting external parameters physics, i.e., short circuit current (J_{SC}), open circuit voltage (V_{OC}), fill factor (FF), and efficiency conversion (Eff). In each layer, the mobility band gap (Eg) was optimized by 1D AFORS-HET software. The optimization results can be used as a basis in the fabrication process.

Solar cells structure and simulation method

Fig. 1(a) show the structure of a-Si:H BFSCs with Glass/TCO/a-Si:H(n)/a-Si:H(i)/a-Si:H(p)/TCO/Glass device contain front and back contacts from TCO (transparent conducting oxide) using ZnO. Fig. 1(b) is an illustration of the distributions of defect states of each layer used in the simulation. Each layer consists band tail defect states describes as conduction and valence band tails have an exponential distribution, while dangling bond states describes as acceptor-like dangling bond and donor-like dangling bond which has Gauss distribution. In the simulation, solar AM1.5 global radiations are considered as the light source with the power density of 100 W/cm^2, while the temperature of the device is maintained at 300 K. Meanwhile, the reflection of light on the front and back contacts in the model was set to be 0.1 and 1, respectively. The other simulation parameters are given in Table 1 [5], [7-11].
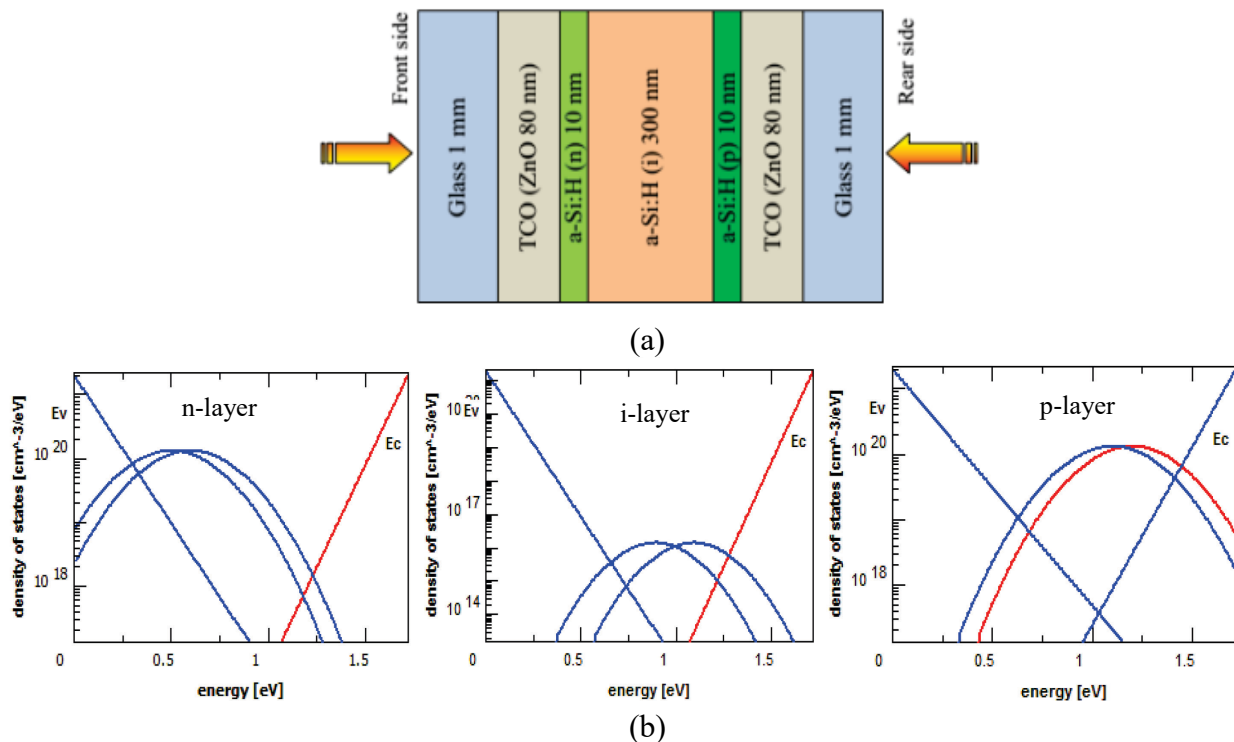

(a)

(b)

Fig. 1 (a) Structure of a-Si:H BFSCs (b) The distribution of defects state for different types of a-Si:H in the simulations.

Table 1 Some initial parameter values for input AFORS-HET simulation.

Parameters	a-Si:H (n)	a-Si:H (i)	a-Si:H (p)
Thickness (nm)	10	300	10
Dielectric constant	11.9	11.9	11.9
Electron affinity (eV)	3.9	3.9	3.9
Band gap (eV, varied)	1.72	1.72	1.72
Optical gap (eV)	1.72	1.72	1.72
Effective conduction and valence band density (cm^{-3})	1.0×10^{20}/ 1.0×10^{20}	1.0×10^{20}/ 1.0×10^{20}	1.0×10^{20}/ 1.0×10^{20}
Acceptor concentration, Na (cm^{-3})	6.89×10^{19}	0	0
Donor concentration, Nd (cm^{-3})	0	1000	7.47×10^{19}
Electron/hole mobility (cm^{2}V^{-1}s^{-1})	20/5	20/5	20/5
Thermal velocity of electron/hole (cms^{-1})	1.0×10^{7}/ 1.0×10^{7}	1.0×10^{6}/ 1.0×10^{6}	1.0×10^{7}/ 1.0×10^{7}
Layer density (gcm^{-3})	2.328	2.328	2.328

Results and Discussion

First of all, the optimization is done by reviewing the initial parameters of the simulation using input parameters as shown in Table 1, and a light source illuminated both sides (front and rear) of devices. Fig. 2 depicts simulation results in the form of the J-V characteristic curve which describes the performance of a-Si:H BFSCs before modifying the band gap of each layer.
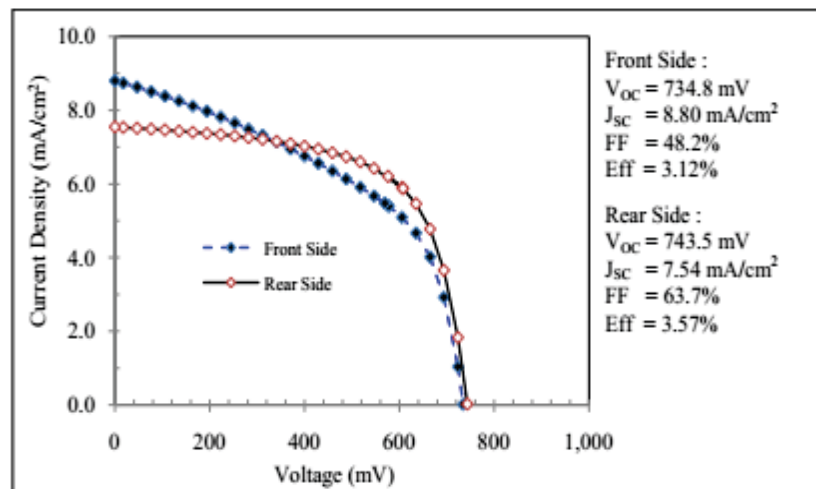

Fig. 2 J-V curve of the simulated a-Si:H BFSCs using default parameters in Table 1 for illuminated front and rear sides .

Fig. 3(a) gives the values of V_{OC}, J_{SC}, FF, and η as a function of band gaps n-layer a-Si:H BFSCs. The simulation is done by referring to Table 1, except for the n-layer band gap which is varied from 1.60 to 2.4 eV. At the beginning of the simulation, the front side values of V_{OC}, J_{SC}, FF, and Eff has the same tendency, which is small fluctuations in the band gap range between 1.60 to 1.78 eV, then it increases sharply in the range of 1.87 to 2.22 eV, and finally stabilizes with increasing band gap n-layer. On the other hand, the rear side shows all the values of V_{OC}, J_{SC}, FF, and Eff fluctuate small and tend to be constant for the entire band gap range. Reach V_{OC} significantly increase between 735 to 767 mV (front side) and 743 to 755 mV (rear side). Different things happened to J_{SC} produced by the front side and rear side, where there was an increase in J_{SC} for the front side between 8.8 to 11.4 mA/cm^2, while the rear side tendency remained constant at 7.6 mA/cm^2. The evolution of the V_{OC} and J_{SC} directly affected to the FF value, where significant changes were observed for the front side with an increase from 46.4 to 76.7%, while for the rear side there was a small increase from 63 to 73.5% in the n-layer band gap range. The maximum

efficiency achieved is 6.4% (front side) and 3.9% (rear side) at 2.0 eV. Therefore, we conclude that 2.0 eV is the optimized result for the n-layer band gap.
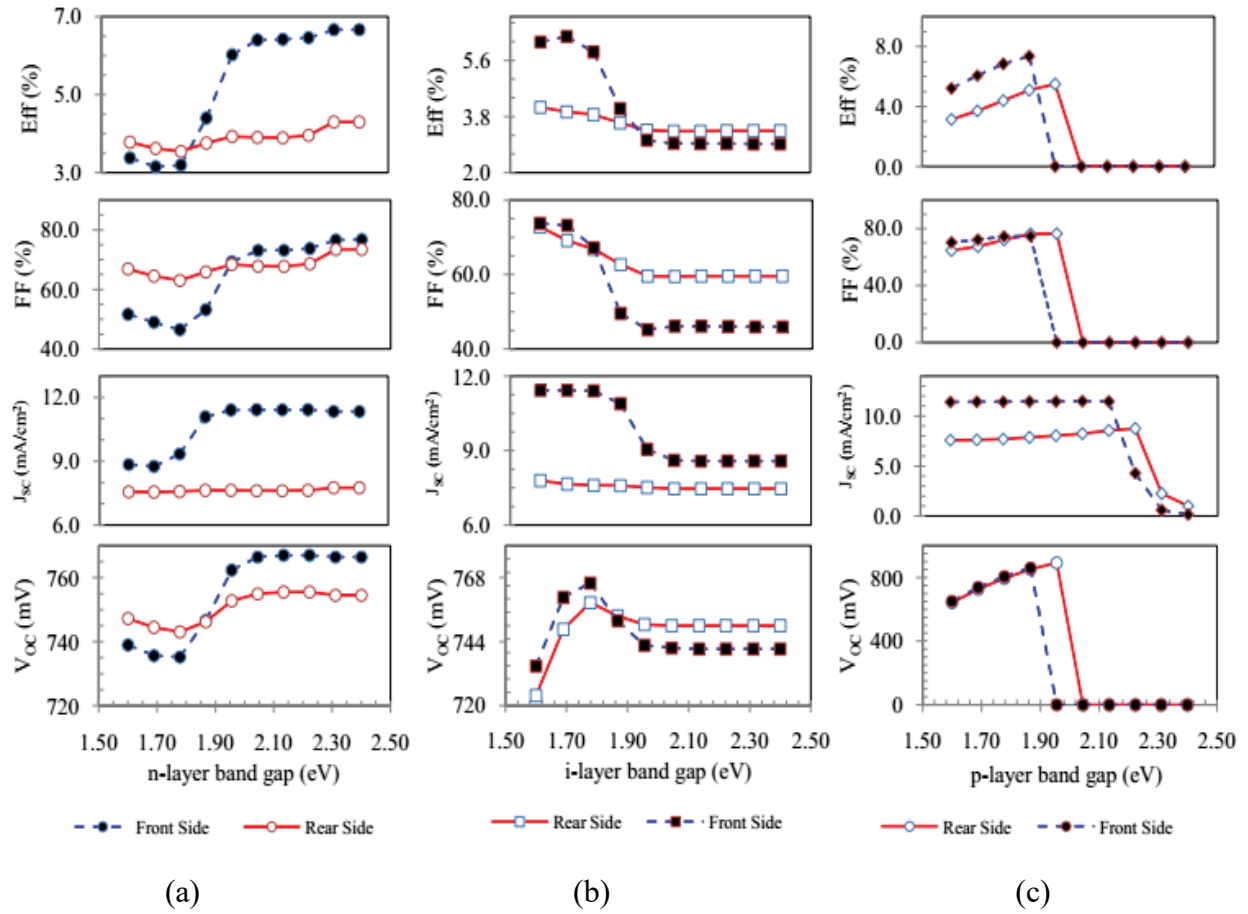

Fig. 3 Variations of V_{OC}, J_{SC}, FF, and Eff for different –n, -i and –p layers band gap of a-Si:H BFSCs which illuminated at the front and rear sides.

The band gap optimization of i-layer is done by setting between 1.60 to 2.4 eV, while -n and -p layers band gap are fixed at 2.0 eV and 1.72 eV. Fig. 3(b) depicts the variation of V_{OC}, J_{SC}, FF, and Eff as a function of i-layer band gap. The V_{OC} value for front side (rear side) illuminated continuously increases with increasing i-layer band gap between 735 to 766 mV (724 to 759 mV) in the band gap range between 1.60 to 1.78 eV and the band gap energy interval between 1.87 to 2.1 eV down to the value of 741 mV (750 mV), then remaining constant with increasing of the i-layer band gap. The increasing of V_{OC} is due to the reduction of the electron-hole pair generation and proper splitting of quasi Fermi level as a result of moving electrons and holes in each layer before the recombination process. On the other hand, J_{SC} experienced a small increase and tended to be constant in the range between 1.60 to 1.78 eV for front side (rear side) illuminated with the maximum current density reached up to 11.44 mA/cm^2 (7.6 mA/cm^2), while in the range 1.87 eV and beyond, J_{SC} tend to be constant at values 8.71 mA/cm^2 (7.5 mA/cm^2). The number of photons absorbed with energy below the band gap will decrease, so the number of electron-hole pairs produced is less which resulted in deterioration in the J_{SC} values. The evolution of FF values between 1.60 to 2.4 eV are decline of 73.7% to 46.0% (front side) and 72.8% to 59.6% (rear side), respectively. The tendency of the Eff has the same trend as FF, the maximum Eff when the band gap is 1.70 eV are around 6.4% for the front side and 4.0% for rear side, respectively. Hence, the optimized band gap for better performance of a-Si:H BFSCs is 1.70 eV.

During the p-layer simulation process, the band gap value of -p layer was varied from 1.60 eV to 2.4 eV, while the band gap of n and i layers are 2.0 and 1.70 eV, respectively. Fig 3(c) shows the simulation results of p layer optimization, V_{OC} increased from 652 to 861 mV for front side and

from 642 to 893 mV for rear side between 1.6 to 1.87 eV but drastically decreased both side V_{OC} to zero after 2.04 eV and beyond, this causes the reduction of electron-hole pair recombination. In the band gap range of 1.60 to 2.13 eV, J_{SC} for both sides tends to be constant at 11.4 mA/cm^2 for the front side and varies from 7.6 to 8.7 mA/cm^2 for the rear side, respectively. The *FF* value in the range of band gap between 1.60 to 1.87 eV tends to be slightly increased to 74.6% for the front side between 1.60 to 1.96 eV to 76.4% for the rear side, then the value of FF drastically decreased up to 0% after the energy gap above 1.96 eV for both sides. The maximum value of *Eff* is 7.4% for the front side, and around 5.1% for the rear side with the band gap p-layer is 2.0 eV.

Table 2 Summarized optimized values of band gap energy for bifacial solar cells.

Layer	Thickness (nm)	Band gap (eV)	Doping (cm^{-3})
-n	10	2.0	6.89 x 10^{19}
-i	300	1.7	1000
-p	10	2.0	7.47 x 10^{19}

Table 2 is results of the optimization process of band gap energy for bifacial solar cells by referring to this parameters; an optimization process is carried out to get the best efficiency that can be used as a benchmark in producing solar cells. The simulation results are shown in Fig. 4. By comparing the final simulation results with the initial parameter using AFORS-HET (Fig.2), we found that a significant increase of V_{OC}, J_{SC}, *FF,* and *Eff* of initial state indicating that efforts to increase the electrical parameters bifacial cell solar has been successfully carried out.
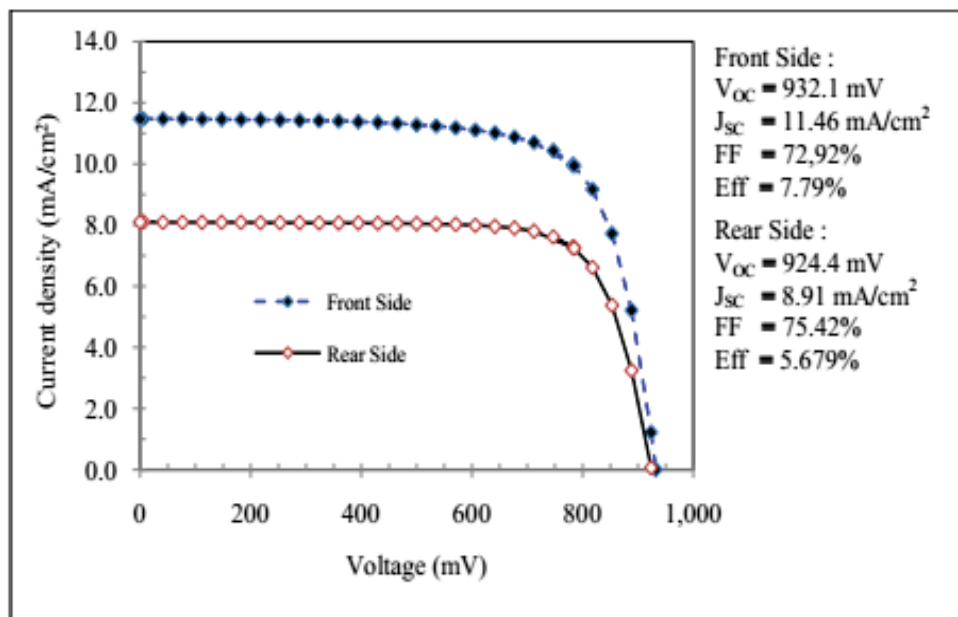

Fig. 4 J-V curve of fully optimized a-Si:H BFSCs using parameters in Tables 1-2, illuminated from the front and rear sides.

Conclusions

In this study, the performance of a-Si:H BFSCs with structure Glass/TCO/a-Si:H(n)/a-Si:H(i)/a-Si:H(p)/TCO/Glass was investigated by using AFORS-HET for optimized. The optimization results show that the optimum band gap for -n, -i and -p layers are 2.0, 1.7 and 2.0 eV, respectively. By comparing the simulation results early on the final simulation show that a significant increase V_{OC}, J_{SC}, FF and *Eff* for both side of a-SI:H BFSCs. Finally, the maximum efficiency obtained from bifacial solar cells based a-Si:H is 7.79% for the front side and 5.68% for the rear side, respectively.

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