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Effect of structural variations in amorphous silicon based single and multi-junction solar cells from numerical analysis

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***Abstract*— In this Work, single and multi-junction solar cells based on hydrogenated amorphous silicon (a-Si:H) and its alloy amorphous silicon carbide (a-SiC:H) are analyzed using one dimensional simulator AMPS- 1D (Analysis of Microelectronic and Photonic Structures). Effects of thickness and doping concentration of different layers as well as the operating temperature on cell efficiency have been investigated with a view to find a more efficient and stable cell. For the single junction cell, the maximum efficiency of 19.62% has been achieved for a thickness of 500 nm of i-layer, which further improved to 20.8% after the optimization of the doping concentration. In case of double junction cell, the highest efficiency of 20.19% was found for top i-layer thickness of 700 nm after optimizing the bottom cell parameters. For the triple junction cell, parameters of the bottom cell and middle cell were optimized and the maximum efficiency of 21.89% was found with the top i-layer thickness of 600 nm. As regards the operating temperature, the double junction and the triple junction tandem cells showed better stability, with temperature gradient of 0.17% and 0.18%/C, respectively, than the single junction cell of 0.23%/C. The overall investigation on amorphous silicon solar cells as done here gives potential parametric suggestion that may lead to the fabrication of the high efficiency and stabilized a-Si thin film solar cells.**

***Keywords*— Amorphous silicon a-SiC:H a-Si:H Single junction Double junction Triple junction Temperature gradient AMPS-1D**

1.Introduction:

The use of thin film technology for the fabrication of solar cells has gradually been increasing for lower production costs and acceptable efficiencies compared to other kinds of solar cells [1]. The energy conversion efficiency of a solar cell can be significantly increased with the improvement of material properties and the designs or structures of the cells. Hydrogenated amorphous silicon (a-Si:H) and its alloys have become important semiconductor materials for solar cells due to lower cost and the ease of fabrication merits [2]. Heterojunction solar cells,where two different materials with different bandgaps form a junction, also proved to be more efficient.Hydrogenated amorphous silicon carbide (a-SiC:H) has the use ful property that its silicon content can be changed by changing the preparation conditions ,e.g., by varying the ratio of silane and methane gases in the mixture.This way the optical bandgap of a-SiC:H can be controlled over a wide range of 1.8–3eV,which proves to be very useful in tailoring solar cells. However,ina-SiC:H the defect density increases with the increase of carbon content ,resulting in a reduction of the photoconductivity. For a-SiC:H films with an optical bandgap between 1.8 and 2.0eV,the photoconductivity and the photo-sensitivity were10E-04 Scm^{-1} and 10E+06,respectively.How- ever, the photoconductivity of the a-SiC:H films with an optical band gap above 2.2eV were about 10E-10 Scm^{-1}. a-SiC:H has been used in the top layers of the single and multijunction approaches since the bandgap of these alloys can be continuously tuned from1.7 to more than 2.7eV [3]. The ideal thin film for a window layer should have higher carrier concentration than silicon absorber,low resistively and high mobility.The a-SiC:H films have been widely investigated as a material with wide band gap [4]. In this study,we investigated a single junction solar cell with the structure SnO2/a-SiC:H/a-Si:H/a-Si:H/ZnO/Ag and two tandem cells,a double junction cell with structure SnO2/a-SiC:H/a-Si:H/a-Si: H/a-SiC:H/a-Si:H/a-Si:H/ZnO/Ag and a triple junction cell with structure SnO2/a-SiC:H/a-Si:H/a-Si:H/a-SiC:H/a-Si:H/a-Si:H/a-SiC: H/a-Si:H/a-Si:H/ZnO/Ag thin film solar cells.The single junction cell has the limitation that it can not absorb low energy photons and as such has relatively low efficiency.To over come this limitation, multijunction solar cells,such as double and triple junction solar cells,based on the spectral splitting principle have been devised.In addition to better efficiency,the stacked solar cell also shows better stability as the problem of photodegradation associated with amorphous silicon solar cells is less manifested in it than its single junction counterpart [5].

2. Device simulation

In this work,the one-dimensional numerical analysis software, Analysis of Microelectronic and Photonic Structures (AMPS-1D) simulator has been employed to model and analyze the three cells mentioned before as shown in Fig. 1. The design parameters have been adopted from some standard references [6]. Variation of efficiency, open circuit voltage (Voc), short-circuit current (Jsc) and fill factor (FF) with the variation of thickness and doping concentrations of different layers and the dependence of efficiency on operating temperature have been investigated. The values of different

material parameters used in AMPS-1D are shown in Tables 1and 2.

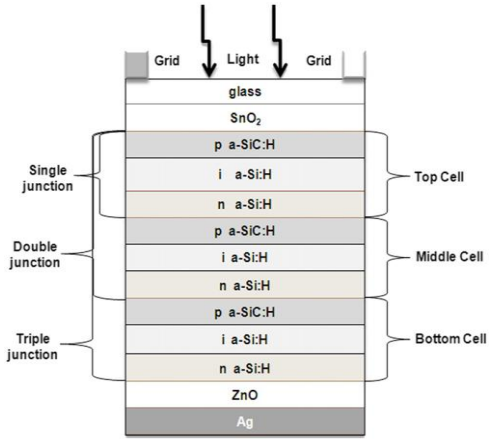

Fig. 1. Structural view of a-Si based solar cells with various configuration (generalized).

At the beginning of constructing a solar cell in AMPS-1D, one has to choose the simulation mode either in density of states (DOS) model or lifetime model. The DOS model is important when dealing with materials that have significant defect densities such as amorphous silicon [7]. The operating temperature is set initially at 300 K. The front contact and back contact of the model have been inserted that are commonly used. General layer parameters have been inserted and are varied with different type of layers. After setting all the parameters, simulation was carried out and the results were compared.

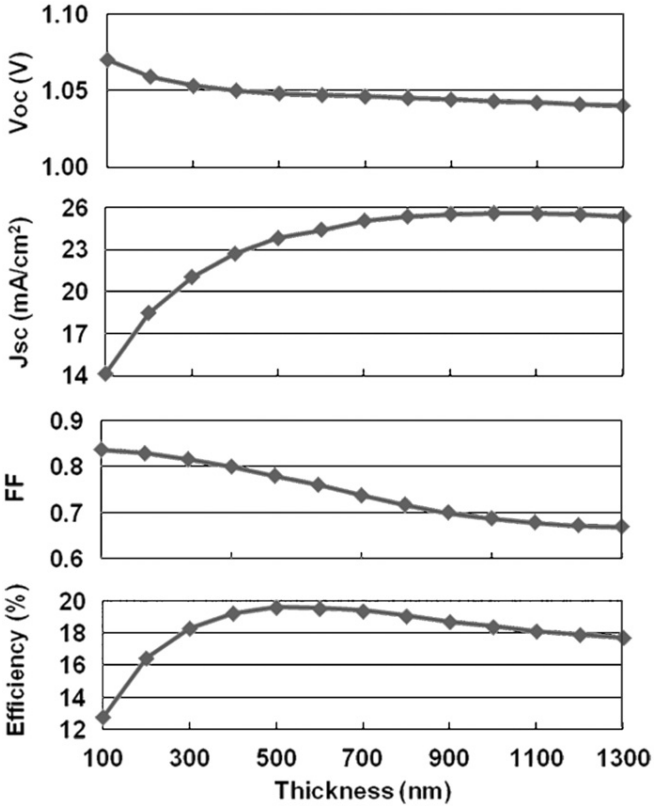

Fig. 2. Effect of i-layer thickness in single junction cell performance.

Table 1 different parametric value as used in the simulation.

	p-layer a-SiC:H	i-layer a-Si:H	n-layer a-Si:H
Relative permittivity, ε_r	11.9	11.9	11.9
Electron mobility, μ_n ($cm^2/V\,s$)	10.0	20.0	20.0
Hole mobility, μ_p ($cm^2/V\,s$)	1.0	2.0	2.0
Acceptor/donor concentration (cm^{-3})	$N_A=3.0\times10^{13}$–3.0×10^{22}	-	$N_D=8.0\times10^{13}$–8.0×10^{22}
Band gap (eV)	1.9–2.0	1.65–1.85	1.65–1.85
Electron affinity (eV)	3.7	3.8	3.8

Table 2 General layer parameters as used in the simulation.

Front contact		Back contact	
Barrier height (φ_{bo})	1.9 eV	Barrier height (φ_{bL})	0.03 eV
Electron recombination velocity, SNO	1×10^7 cm/s	Electron recombination velocity, SLN	1×10^7 cm/s
Hole recombination velocity, SPO	1×10^7 cm/s	Hole recombination velocity, SPL	1×10^7 cm/s
Reflection coefficient, RF	0.2	Reflection coefficient, RB	0.9

3. Results and discussion

3.1.Single junction solar cell

In p–i–n single junction solar cell,p-layer should be as thin as possible to allow maximum light in to the following layers .To find the optimum structure,the i-layer thickness was varied from 100 to1300 nm,and the highest efficiency of 19.62% was obtained at a i-layer thickness of 500nm as can be found in Fig. 2. FF and Voc gradually decreased with the increase of i-layer thickness. The substantial fall in Voc with the increase of i-layer thickness can possibly correlate to the associated increase of defect densities.Higher defect densities affect the electric field and carrier collection,eventually yielding in poor Voc [8]. This decrease inVoc might be averted with the introduction of a wide band gap buffer layer,which reduces shunt resistance and prevents leakage current through the p/I interface and i/n inter- face [9]. Jsc monotonically increased up to 800nm and then reached saturation.

3.2. Effect of acceptor and donor concentration in performance

The efficiency of the single junction solar cell increased with the increase of both the acceptor concentration and donor concentration. The efficiency reached its highest value of 20.47% at a acceptor concentration of $3.0x10^{19}$ cm^{-3} as shown in Fig. 3 and the highest value of 20.8% at a donor concentration of $8.0x10^{20}$ cm^{-3} as seen in Fig. 4. Higher donor concentration excites more electrons to conduction band and higher acceptor concentrations provides more holes to produce better conductivity and photocurrent generation thereby increasing efficiency.

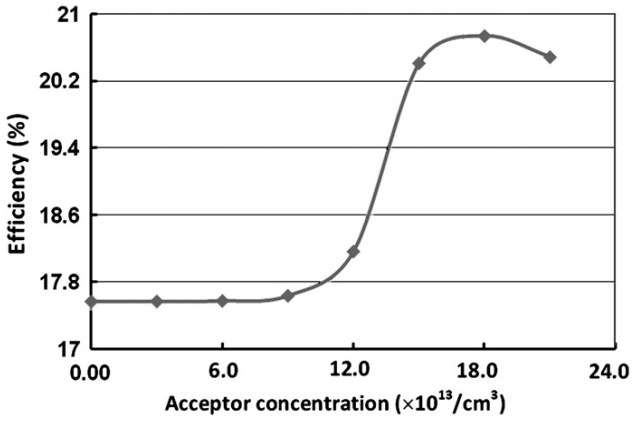

Fig. 3. Effect ofacceptor concentration (p-layer)on cell efficiency.

3.3. Double junction configuration

Fig. 5 shows the variation of Voc ,Jsc , FF and efficiency in double junction solar cell with the change of i-layer thickness of the top cell from 100 to 1300nm,where the i-layer thickness of the bottom cell is fixed at 100nm.The highest efficiency of

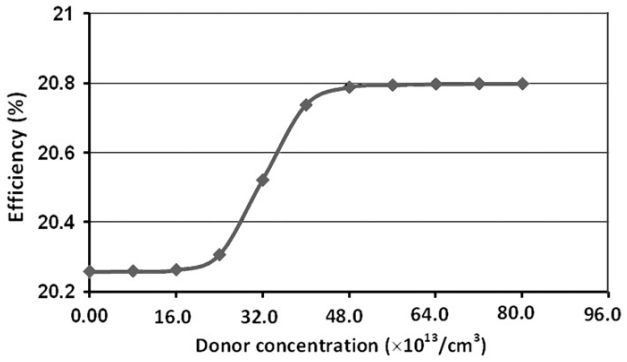

Fig. 4. Effect of donor concentration (n-layer) on cell efficiency.

20.19% was found at a thickness of around 700nm. FF showed a decreasing trend with the increase i-layer thickness ,whereas Voc increased upto 700 nm and then decreased slowly.

3.4. Triple junction configuration

Fig. 6 shows the performance of the triple junction solar cell with the variation of i-layer thickness in the range 100–1300nm, where the thickness of the i-layers of both middle and bottom cells are fixed at 100nm.Higher efficiency was obtained in the range 400–700nm,and the maximum efficiency of 21.89% was found at a thickness of 600nm.FF gradually decreased up to 1100 nm, whereas Voc increased till 600 nm and decreased there after. However,Jsc increased up to 800nm and then sharply decreased probably due to optical and recombination losses (Fig. 7). It is apparent that the drop of efficiency after 700 nm is associated with the fall of FF and Jsc.

3.5. Spectral response of a-Si solar cells

As mentioned earlier,the method of spectral splitting is implemented in multijunction amorphous silicon solar cells .In our simulated structure ,bandgap was gradually decreased from the top cell to the bottom cell so that the high energy photons could be absorbed in the top cell and lower energy photons could be absorbed in subsequent cells [10]. As a result the multijunction cells yielded better efficiency.

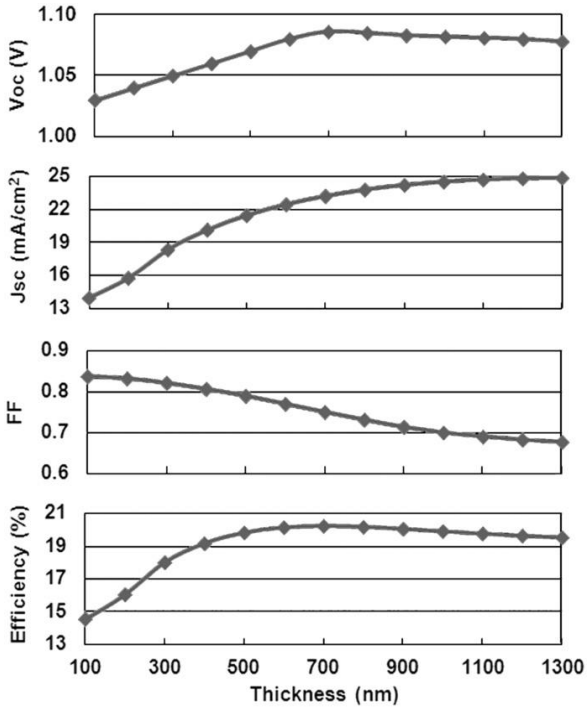

Fig. 5. Effect of top cell's i-layer thickness in performance in double junction cells.

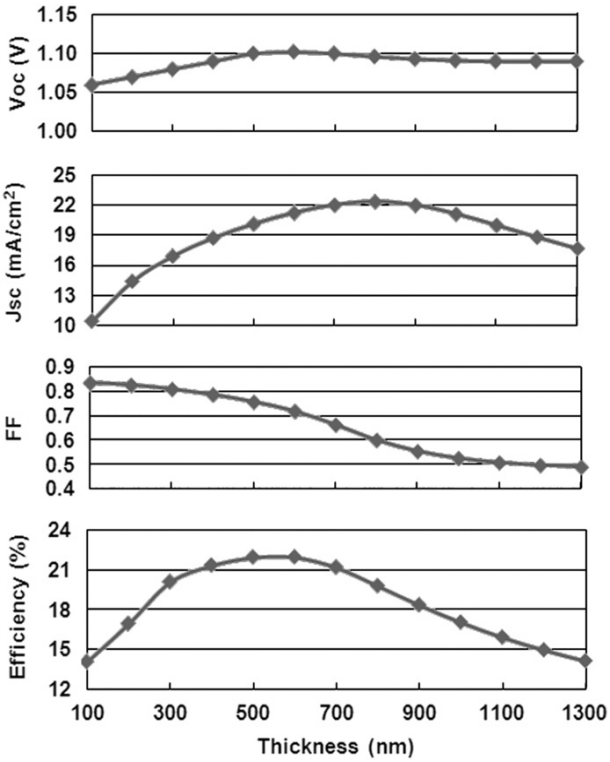

Fig. 6. Effect of top cell's i-layer thickness in performance in triple junction cells.

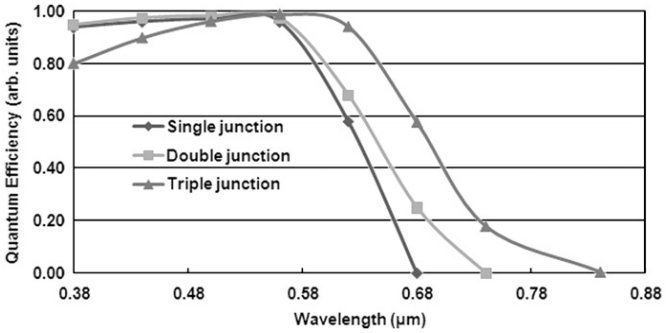

Fig. 7. Quantum efficiency for single and multijunction a-Si solar cells.

3.6. Effect of operating temperature

Fig. 8 demonstrates how the cell performance varied with operating temperature. The double and triple junctions showed better stability with temperature gradient -0.17% and -0.18%/ 1C, respectively .In contrast, the single junction cell showed lower stability with a temperature gradient of -0.23%/1C.

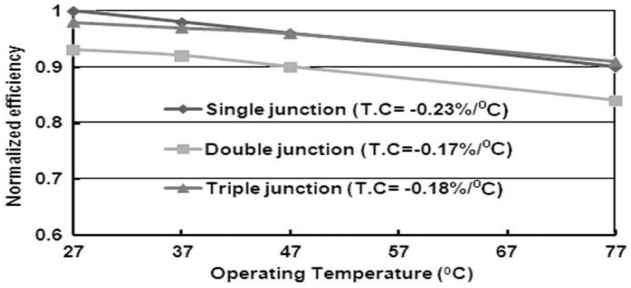

Fig. 8. Operating temperature gradient.

4. Conclusion

In this work,we have modeled and simulated a-Si:H thin-film heterojunction single and tandem cells using AMPS-1D. From the simulation, the efficiencies of the single junction ,double junction and triple junction cells are found to be19.62%,20.19% and 21.89%, respectively.Temperature gradients of the cells are found to be _0.23%, _0.17% and _0.18%/1C, in the same order .Hence, the simulation results corroborate the established fact that tandem amorphous silicon solar cells give better efficiency and stability than their single junction counter part. This in turns exerts the validity of the simulation,which might be used further to explore in novel solar cell configurations.

References

[1] Allan Gregg, Richard Blieden, Alen Chang Herman Ng, Performance analysis of large scale, amorphous silicon photovoltaic power systems, Photovoltaic Specialist Conference and Exhibition, January 3–7, FL, USA, 2005.
[2] Jeffrey Yang, Arindam Banerjee, Subhendu Guha, Amorphous silicon based photvoltaics-from earth to the ‘‘final frontier, Sol. Energy Mater. Sol. Cells 78 (2003) 597–612.
[3] N. Andoh, H. Nagayoshi, T. Kanbashi, K. Kamisako, Characterization of high quality a-SiC:H films prepared by hydrogen radical CVD method, Sol. Energy Mater. Sol. Cells 49 (1997) 89–94.
[4] Y.T. Kim, B. Hong, G.E. Jang, S.J. Suh, D.H. Yoon, Charaterization of a-SiC:H films deposited by RF plasma CVD, Cryst. Res. Technol. 37 (2002) 219–224.
[5] Liwei Li, Young Kee Chae, Shuran Sheng, Tae Kyung Won, Ankur Kadam, Jerry Chen, Soo Young Choi, John M. White, a-Si:H single junction and a-Si:H/C-Si:H tandem solar cells fabrication using large area (5.7m2) PECVD system, Technical Digest of the international PVSEC-17,Fukuoka,Japan,2007, p. 345–346.
[6] S.V. FonAsh, J. Arch, J. Cuiffi, J. Hou, W. Howland, P. McElheny, A. Moquin, M. Rogossky, F. Rubinelli, T. Tran, H. Zhu, in: A Manual for AMPS-1D for Windows 95/NT; A One-Dimensional Device Simulation Program for the Analysis of Microelectronic and Photonic Structures, Pennsylvania State University, USA, 1997.
[7] Richard H. Bube, in: Photovoltaic Materials, Imperial College Press, UK, 1998, p. 68–91.
[8] D. Lundszien, F. Finger, H. Wagner, a-Si:H buffer in a a-SiGe:H solar cells, Sol. Energy Mater. Sol. Cells 74 (2002) 365–372.
[9] B. Rech, H. Wagner, Potential of amorphous soilicon for solar cells, Appl. Phys. A 69 (1999) 155–167.
[10] M. Zeman, J.A. Willemen, L.L.A. Vosteen, G. Tao, J.W. Metselaar, Computer modelling of current matching in a-Si:H/a-Si:H tandem solar cells on textured TCo substrates, Sol. Energy Mater. Sol. Cells 46 (1997) 81–99.