Effect of Energy Bandgap of the Amorphous Silicon Carbide (A-Sic: H) Layers On A-Si Multijuntion Solar Cells from Numerical Analysis

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Abstract: - In this work, single and multijunction amorphous silicon carbide (a-SiC:H) thin film solar cells have been investigated by the Analysis of Microelectronic and Photonic Structures (AMPS 1D) simulator in respect to overall performance. The photovoltaic characteristics have been observed by changing the optical energy bandgap of p-layer. For single junction, a good efficiency trend has been found for the window layer energy bandgap of 1.8-2.2 eV and the highest efficiency is achieved to be 17.67% at 2 eV. In the case of double junction, the efficiency has been found for the second p-layer energy bandgap of 1.8-2 eV and the highest efficiency is 19.04% at 1.9 eV. On the other hand, for triple junction solar cell the maximum efficiency has been found for the bottom cell's p-layer energy bandgap of 1.7-1.9 eV and the highest efficiency is 20.42% at 1.8 eV. It is evident that the optimum energy bandgap for a-SiC:H as window layers in triple junction configuration is 1.8-2.1 eV.

Key-Words: - Thin-film, single junction, multijunction, a-SiC: H, bandgap and AMPS-1D.

1 Introduction

The use of thin film technology for the fabrication of solar cells has gradually been increasing for lower production cost and acceptable efficiencies compared to other kinds of solar cells [1]. The conversion efficiency of a solar cell can be increased significantly with the improvement of materials properties and subsequently the designs and structures of the cell. Hydrogenated amorphous silicon (a-Si:H) alloy has become one of the important semiconductor materials for solar cells due to its low cost and the easy fabrication process. Heterojunction solar cells, where two different materials with different bandgaps form a junction, are of great interest to many researchers. Doped and intrinsic hydrogenated amorphous silicon (a-Si:H) with a bandgap 1.7 eV are some of the choices for fabricating such a cell on silicon. The window layers with a bandgap greater than 1.7 eV should transmit more photons to the absorber, in turn increasing the efficiency of the a-si solar cell [2]. Hydrogenated amorphous silicon carbide (a-SiC:H) has the useful property that the silicon content can be changed by changing the preparation conditions, especially the ratio of the mixture of silane and methane gases. As a consequence, its properties can be controlled over a wide range (for example, 1.8eV–3eV for the optical band gap). The a-SiC:H and hydrogenated amorphous silicon (a-Si: H) are therefore important materials for optoelectronic devices such as solar cells. However, in a-SiC:H the defect density increases with increase of carbon content, resulting in a reduction of the photoconductivity. For a-SiC:H films with an optical band gap between 1.8eV to 2.0eV, the photoconductivity and the photosensitivity were 10E-04 Scm^{-1} and 10E+06, respectively. However, the photoconductivity of the a-SiC: H films with an optical band gap above 2.2eV were about 10E-10 Scm^{-1}. Hydrogenated amorphous silicon carbide (a-SiC:H) alloys have been used as the top layers of the single and mutijunction approaches since the bandgap of these alloys can be continuously tuned from 1.7 eV to more than 2.7 eV [3, 4]. 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 [5]. In amorphous solar cells, the

films were applied to window layers or the top layers of tandem cells. To achieve improvement of conversion efficiency and reliability in amorphous solar cells, high-quality a-SiC:H are desired. Microcrystalline silicon cells have a relatively low bandgap ranging from 1.3-1.6 eV. Hence, microcrystalline is suitable as the bottom layers of triple and double junction configurations to absorb the red photons i.e., low energetic photons. Moreover, microcrystalline is cheaper than germanium doped layers [6].

In this study, we have designed three types of solar cell models with single, double and triple junctions having the structure of a-SiC:H/a-Si:H/a-Si:H, and a-SiC:H/a-Si:H/a-Si:H/µc-Si:H/µc-Si:H/µc-Si:H and a-SiC:H/a-Si:H/a-Si:H/a-SiC:H/a-Si:H/a-Si:H/a-SiC:H/µc-Si:H/a-Si:H, respectively. In practice, the single junction cell usually can not give higher efficiency due to the leakage of maximum energy utilization of solar energy. For that, we have designed the multijunction solar cells such as double and triple junctions based on the spectral splitting principle so that the maximum energy can be absorbed. Moreover, the light induced degradation i.e., higher instability in single junction leads us to design stacked structure for capturing the solar spectrum efficiently, then it can achieve the maximum conversion efficiency [7].

2 Simulation of the Devices

In this work, a one dimensional numerical analysis tools that stands for Analysis of Microelectronic and Photonic Structures (AMPS-1D) is used to construct the single, double and triple junction solar cell models as well as to obtain their performance once the design parameters are adopted from various practical references [8]. The single and multijunction p-i-n structure solar cell models have been designed and analyzed the performance in respect to the Voc, Jsc and FF and efficiency by incorporating the material parameters into AMPS-1D.

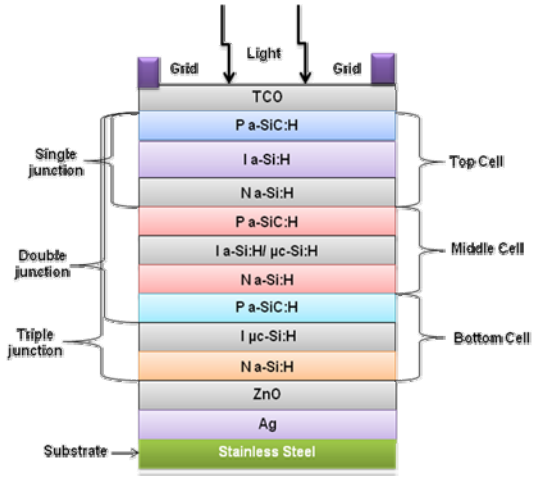

Fig. 1 Structural view of a-Si based solar cells (generalized).

The front contact and back contact of the model have been inserted. General layer parameters have been inserted and are varied with different type of layers. After all the parameters input the simulation has started and the output is obtained.

Table 1 Overall electronic properties used in simulation.

	P(a-SiC:H)	I (a-Si:H/ µc-Si:H)	N (a-Si:H)
Relative permittivity ε_r	11.9	11.9	11.9
Electron mobility, μ_n (cm^2/v-s)	10.0	20.0/60.0	20.0
Hole mobility, μ_p(cm^2/v-s)	1.0	2.0/6	2.0
Acceptor & donor concentration (cm^{-3})	N_A= $3.0x10^{13}$-$3.0x10^{20}$	-	N_D= $8.0x10^{13}$-$8.0x10^{20}$
Bandgap (eV)	1.8-2.6	1.65-1.85/1.3-1.6	1.65-1.85
Effective density of states in conduction band (cm^{-3})	$2.5x10^{20}$	$2.5x10^{20}$	$2.5x10^{20}$
Effective density of states in valance band (cm^{-3})	$2.5x10^{20}$	$2.5x10^{20}$	$2.5x10^{20}$
Electron affinity(eV)	3.7	3.8	3.8

Table 2 General layer parameters.

Front Contact	Back Contact
PHIBO= 1.9 eV	PHIBL= 0.03 eV
SNO= $1x10^7$ cm/s	SLN= $1x10^7$ cm/s
SPO= $1x10^7$ cm/s	SPL= $1x10^7$ cm/s
RF= 0.0	RB= 0.9

3 Results and Discussion

3.1 Single Junction Solar Cell

To find the optimum structure of single junction a-Si solar cells, the bandgap of a-SiC:H window layer has been varied from the range of 1.8 eV to 2.6 eV. The effect of Bandgap on cell performance is shown in Fig. 2. The highest efficiency of 17.66% has been achieved at 2.0 eV. The Voc, Jsc and FF of this model gradually decrease from 2.2 eV. Hence the efficiency decreases sharply after the bandgap of 2.2 eV due to the decrease of photoconductivity and photosensitivity.

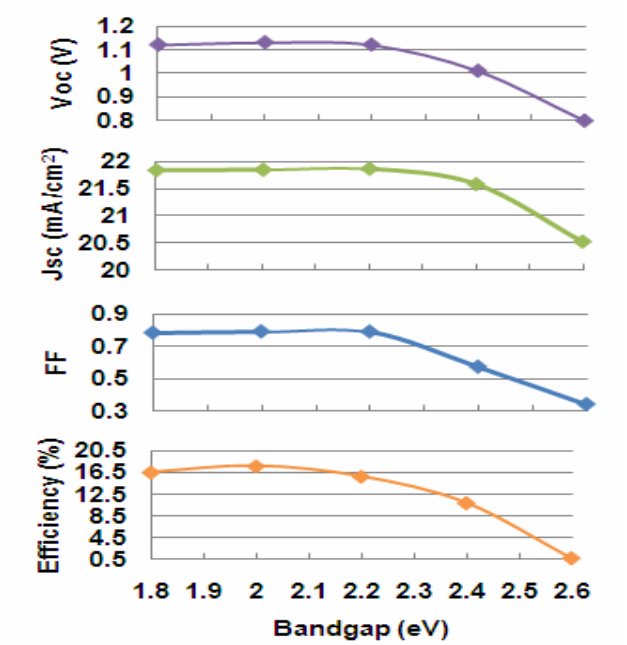

Fig. 2 Effect of bandgap in cell performance for single junction cells.

3.2 Double Junction Model

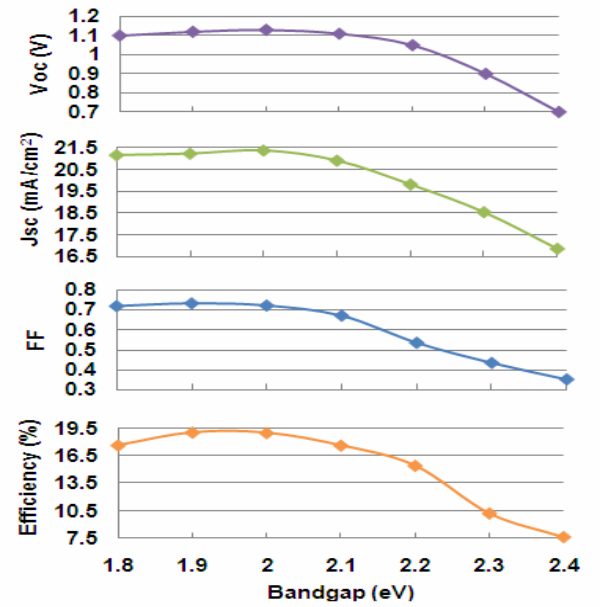

Fig.3 Effect of bandgap in cell performance for double junction cells.

Fig. 3 shows the variation of efficiencies in double junction configuration with the change of middle cell's p-layer energy bandgap of 1.8-2.4 eV. The highest efficiency of 19.04% has been found for this cell at the bandgap of 1.9 eV. When the bandgap increase more than 2.1 eV, the cell efficiency decreases rapidly due to the decrease of the Voc, Jsc and FF. Furthermore, with the increase of bandgap more than 2.2 eV by increasing carbon content the defect density increases and hence photoconductivity decreases. The efficiency at 1.9 eV and 2.3 eV are 19.043 % and 10.23%, respectively.

3.3 Triple Junction Model

Bandgap of each layer has to decrease from top to bottom cell's to absorb various types of energetic photons. Fig. 4 illustrates the cell performance with the variation of bottom cell's p-layer bandgap range of 1.7-2.3 eV. It has been found that the efficiency trend is quite good for the bottom cell's p-layer bandgap range of 1.7 eV to 1.9 eV. After that the efficiency falls rapidly due to the decrease of Jsc and FF. Obviously, in triple junction configuration the bottom cell get the chance to convert the low energetic photons into electron-hole pairs that are passing through the top cells.

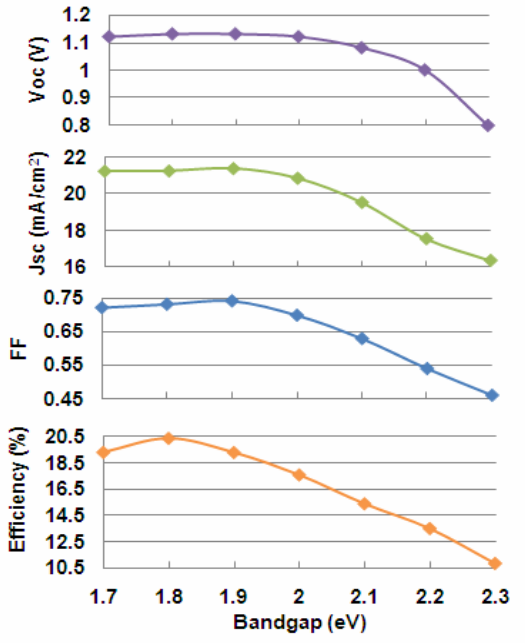

Fig.4 Effect of bandgap in cell performance in

triple junction cells.

4 Conclusion

For single junction, the maximum efficiency of 17.66% has been achieved for p-layer bandgap of 2 eV. For double junction a-Si solar cells, the highest efficiency of 19.04% has been found for middle cell's p-layer bandgap of 1.9 eV and a-Si triple junction cell shows the highest efficiency of 20.42% with the bottom cell's p-layer bandgap of 1.8 eV. It is evident from this numerical simulation that the triple junction structure with the proposed configuration shows the best performance compared with the single and double junction configurations. The simulation results shows that the optimum energy bandgap for a-SiC:H as window layers in triple junction configuration is 1.8-2.1 eV. Moreover, different studies show that the photoconductivity and photosensitivity of the a-SiC:H thin film improves at the optical bandgap range of 1.8 eV to 2 eV. On the other hand, with the increase of carbon content in the alloy of a-SiC:H the energy bandgap can easily be increased but the photoconductivity will decrease when the bandgap is more than 2.2 eV. For the comparison of simulated and practical implementation, these three models can be tried in laboratory for practical implementation in order to achieve higher practical performance at cost-effective fabrication processes.

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