International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-2, Issue-12, December 2015

Improving Efficiency of an Amorphous Silicon (p-a-SiC:H/i-a-Si:H/n-a-Si:H) Solar Cell by Affecting Bandgap and Thickness from Numerical Analysis

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Abstract— **In this investigation hydrogenated amorphous silicon carbide (a-SiC:H) solar cell has been investigated and characterized by using the Analysis of Microelectronics and Photonic Structures (AMPS-1D) simulator. Although some works have been done to simulate this type of solar cell but by affecting the bandgap and thickness to improve the efficiency is the first time investigation which is reflected in this paper. The p-type hydrogenated amorphous silicon carbide (p-a-SiC:H) with the thickness of 15 nm, the hydrogenated interface amorphous silicon (i-a-Si:H) with the thickness of 300 nm and the n-type hydrogenated amorphous silicon (i-a-Si:H) with the thickness of 15 nm are used to obtain the efficiency of 19.649% which is comparatively higher than the conventional Si solar cell's efficiency (11%-14%). Most of the data of this simulation has been transferred to the graph.exe (a graph plotting software) to plot the characteristics curves. This paper provides a new approach of improving the efficiency of hydrogenated amorphous Silicon solar cell.**

Index Terms— **Thin film and a-SiC:H, bandgap, efficiency and AMPS-1D**

I. INTRODUCTION

People all over the world have investigated different type of silicon solar cells for many years. Particularly, amorphous silicon (a-Si) has been favored for investigation compared to crystalline silicon and polysilicon for its better characteristics, such as higher absorption coefficient, better response in low light environment and lower cost [1]. Fabrication of solar cells using thin film technology has gradually been increasing for comparatively lower production cost and acceptable efficiencies [2]. Yet, the Staebler–Wronski effect (S–W effect) of amorphous silicon reduces the conversion efficiency. To reduce the light-induced degradation connected with the porosity of the intrinsic layer of hydrogenated amorphous silicon (a-Si:H) [3]. Hydrogenated amorphous silicon (a-Si:H) alloy has achieve popularity as one of the important semiconductor materials for solar cells because of its low cost and the easy fabrication process [4]. For solar cell applications Hydrogenated amorphous silicon (hereafter, a-Si:H) thin film is a good optoelectronic material candidate as its high optical absorption coefficient (>105 cm^{-1}), adjustable bandgap, and low temperature deposition capability. The bandgap of a-Si:H can be tuned from 1.6 to 1.8 eV as the optical bandgap up to 1.7 eV lies near the energy at which high solar energy conversion efficiencies are expected. The conversion efficiency of hydrogenated amorphous silicon (a-Si:H) single-junction thin-film solar cells has gradually been developed from 2.4% [5] to 10.1% [6]. Again, Hydrogenated amorphous silicon carbide (a-SiC:H) has the special property that by changing the preparation conditions, particularly the ratio of the mixture of silane and methane gases the silicon content can be changed. As a result, its properties can be controlled over a wide range (for example, 1.8eV–3eV for the optical band gap). That's why the a-SiC:H and hydrogenated amorphous silicon (a-Si: H) are important materials for optoelectronic devices such as solar cells [4]. There are a number of fabrication methods such as PECVD (RF, VHF, and Microwave), hot-wire CVD, photo CVD, sputtering, ECR CVD, and PBD downstream have been applied for improving cell performance [7, 8]. Among them PECVD is the most effective method for the fabrication of a-Si:H solar cells which has been used for the fabrication of single-junction a-Si:H solar cells [9].

Since the bandgap of Hydrogenated amorphous silicon carbide (a-SiC:H) alloys can be randomly tuned from 1.7 eV to more than 2.7 eV these alloys have been used as the top layers of the single and multifunction approaches [10, 11] . 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 [12]. 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 [13].

In this work, a one dimensional numerical analysis tools that stands for Analysis of Microelectronic and Photonic Structures (AMPS-1D) is used to construct an amorphous Silicon solar cell models as well as to obtain their performance once the design parameters are adopted from various practical references from [14]. We tried to construct a solar cell device with p-a-SiC:H/i-a-Si:H/n-a-Si:H by using strong simulator AMPS-1D and simulate the outstanding efficiency of 19.649%.

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II. MODEL FOR SIMULATION

The density of state (DOS) model is used to simulate our model. The schematic diagram of p-a-SiC:H/i-a-Si:H/n-a-Si:H is shown in Fig. 1.

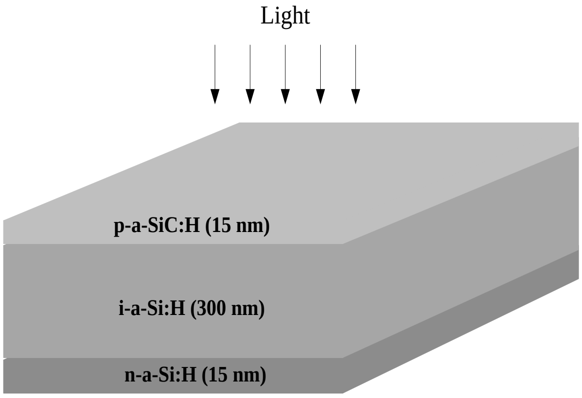

Fig. 1 The schematic diagram of our proposed

In Fig. 1 the thickness of the p-a-SiC:H, i-a-Si:H and n-a-Si:H is 15 nm, 300 nm and 15 nm respectively for which the maximum efficiency is observed. It also has been investigated that the thickness of i-a-Si:H other than 300nm has been decreasing efficiency. The others parameter for the proposed model simulation is shown in Table.1.

Table.1 The electronic properties used for our proposed model simulation

Electronic properties	**p-a-SiC:H**	**i-a-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	100.0	40.0
Hole mobility, μ_p (cm^2/v-s)	1.0	10.0	4.0
Acceptor & donor concentration (cm^{-3})	$N_A=1.0\times10^{20}$	-	$N_D=1.0\times10^{20}$
Bandgap (eV)	2.50	2.60	2.50
Effective density of states in conduction band (cm^{-3})	2.5×10^{20}	2.5×10^{20}	2.5×10^{20}
Effective density of states in valence band (cm^{-3})	2.5×10^{20}	2.5×10^{20}	2.5×10^{20}
Electron affinity(eV)	3.50	3.70	3.70

The front contact and back contact parameters are included in table. 2.

Table. 2 Parameters for front contact and back cntact

Front contact	**Back contact**
PHIBO=1.90 eV	PHIBL=0.02eV
SNO=1.0×10^7 cm/s	SNL=1.0×10^7 cm/s
SPO=1.0×10^7 cm/s	SPL=1.0×10^7 cm/s
RF=0.00	RB=0.90

III. SIMULATION

For the simulation, the parameters in Table.1 and Table. 2 are used. The temperature is used 300K as default and AM 1.5 illuminations are used to get the all results.

IV. RESULT AND DISCUSSION

The short circuit current is defined as the current when the load of a solar cell is replaced by a short-circuit. As a result the current will be maximum and voltage will be zero across that solar cell. The short circuit current increases with light intensity. Again short circuit current density is defined as the ratio of short circuit current and area of the solar cell. The more the area of solar cell means more photon absorption which means more short circuit current because of increasing electron release. So, the short circuit current of a solar cell is proportional to the area of it. But the short circuit current density of a solar cell is inversely proportional to the area of it. The short circuit current density is a very important term for any solar cell in order to get the desired output. The following Fig. 2 shows the short-circuit current density versus bandgap of p-a-SiC:H and n-aSi:H.

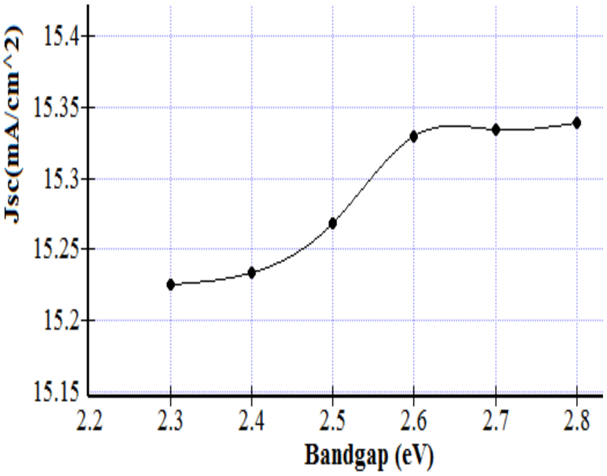

Fig. 2 Bandgap vs short circuit current density curve

From the Fig. 2 it is observed that, as the bandgap of each p-a-SiC:H and n-aSi:H layer is increased, the short circuit current density is also increasing. It has been observed from the graph that the short-circuit current density (J_{sc}) is maximum at bandgap of 2.60 eV of each p-a-SiC:H and n-aSi:H layer. This bandgap also has an effect on the device open circuit voltage which is shown in Fig. 3.

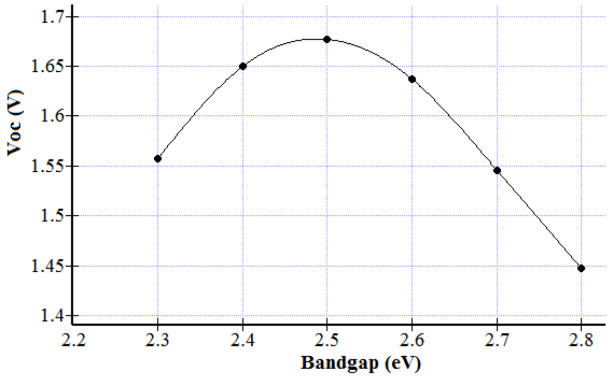

Fig. 3 Bandgap vs open circuit voltage of the proposed model.

From Fig. 3 it has been observed that at bandgap of 2.50 eV of each p-a-SiC:H and n-aSi:H layer, the open circuit voltage is maximum. Any bandgap other this has a detrimental effect on decreasing the open circuit voltage as Fig. 3 shows that. Work has been included with increasing short circuit density and open circuit voltage to optimize the efficiency at a particular bandgap of 2.50 eV which is discussed above.

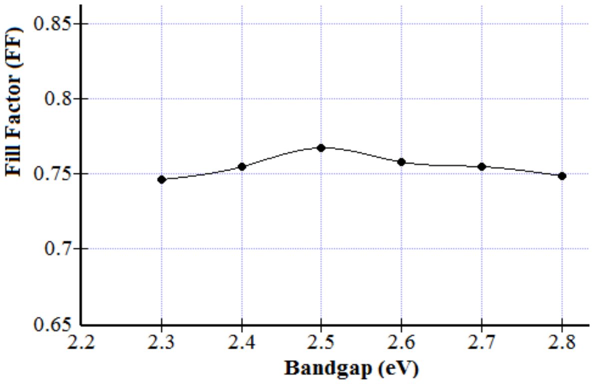

Fig. 4 Bandgap vs FF curve of the model

The following Fig. 4 shows the Bandgap of each p-a-SiC:H and n-aSi:H layer vs fill factor curve. The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The ‘fill factor’, more commonly known by its abbreviation ‘FF’, is a parameter which, in conjunction with V_{oc} and J_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and J_{sc}. It has been observed from simulation that at 2.50 ev bandgap the FF is maximum which is 0.767.

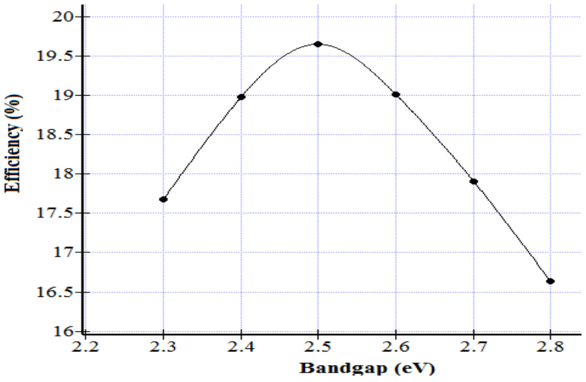

Fig. 5 Bandgap (eV) vs efficiency (%) curve

The effect of bandgap of different layer on efficiency is very important as shown from Fig. 5. We have been tried to simulate this model with increasing the bandgap of each p-a-SiC:H and n-aSi:H layer from 2.30 eV to 2.80 eV in order to optimize the efficiency. It has been observed that at 2.50 eV of bandgap the efficiency is maximum which is 19.649%.

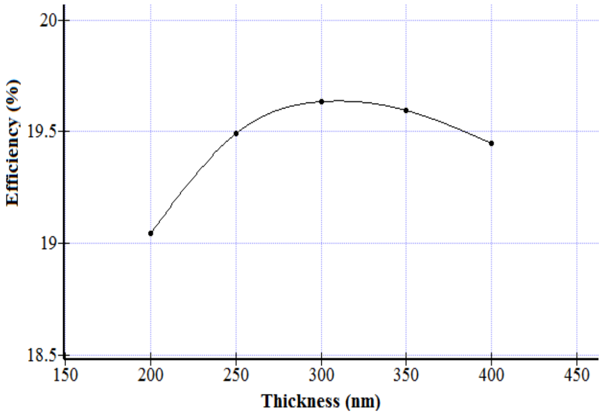

Fig. 6 Thickness of i-a-Si:H (nm) vs efficiency (%) curve of proposed model.

The several simulation results show this outstanding curve that, at 300 nm thickness of i-a-Si:H the efficiency is the highest (19.649%) at 2.60 eV bandgap. A current-voltage (J-V) curve shows the possible combinations of current and voltage output of a photovoltaic (PV) device. A solar cell device, such as a solar module, produces its maximum current when there is no resistance in the circuit, i.e., when there is a short circuit between its positive and negative terminals. This maximum current is known as the short circuit current and is abbreviated J_{sc}. When the module is shorted, the voltage in the circuit is zero. Conversely, the maximum voltage occurs when there is a break in the circuit. This is called the open circuit voltage (Voc). Under this condition the resistance is infinitely high and there is no current, since the circuit is incomplete. The proposed model J-V and P-V characteristics curves has been observed at light ON mode which is shown in following Fig. 7.

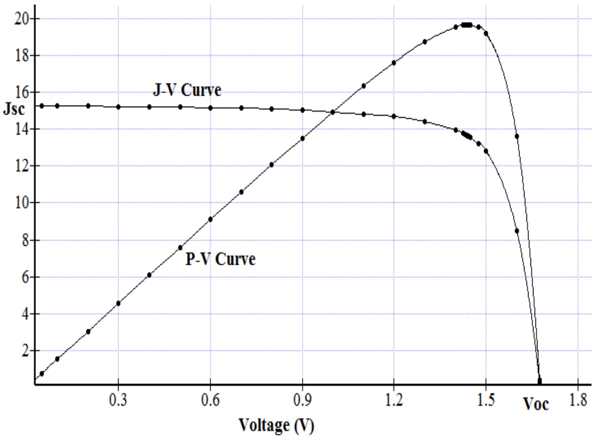

Fig. 7 Desired J-V and P-V characteristics curves of our proposed model

The simulation result shows the J-V characteristics with short circuit current density, J_{sc}=15.269 mA/cm^2, Efficiency, η=19.649%, fill factor, FF=0.767 and open circuit voltage, V_{oc}=1.677 V. The maximum power has been obtained from this simulation is 19.649 mW/cm^2, strictly speaking high performance.

V. CONCLUSION

To recapitulate, the efficiency, η=19.649% has been observed at 300 nm of thickness of i-a-Si:H (2.60 eV) and at 15 nm thickness of each p-a-SiC:H and n-aSi:H layer (2.50 eV). This works has been involved to increase the efficiency by controlling different parameters. This (19.649%) efficiency is obviously higher than the conventional Silicon solar cell's efficiency (11%-14%). The donor and acceptor density less than 10^{20} cm^{-3} drastically affect the efficiency of the proposed device. By controlling the growth parameter such as band tail state, band gap state, doping density and interface recombination velocity we can enhance the efficiency. This simulated model can be tried to fabricate into laboratory in order to implement and compare with simulation result and for better performance.

ACKNOWLEDGMENT

The authors would like to thank to the Pennsylvania State University, USA, for providing us the Analysis of Microelectronic and Photonic Structures of one dimensional device (AMPS-1D) simulation package.

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