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Modeling and Simulation of Highly Efficient Amorphous Silicon Single Junction Solar Cell

***Md. Asif Siddique[1], Md. Kamrul Hasan[2], M. A. Matin[3], Nowshad Amin[4] and Md. Mamunur Rahman[5]**

[1]B.Sc. in EEE, CUET, asifsiddiquebzs@gmail.com
[2]B.Sc. in EEE, CUET, kamrul21cuet@gmail.com
[3]Professor, Department of EEE, CUET, imamatin@yahoo.com
[4]Professor, Department of Electrical, Electronic and Systems Engineering,
UKM, Malaysia, nowshad@ukm.edu.my
[5]B.Sc. in EEE, CUET, md.mamunurrahman37@yahoo.com

Abstract*-Amorphous silicon (a-Si) is one of most significant solar cell materials for its material properties. In this paper, Single junction solar cell has been analyzed, designed and investigated by the popular solar cell simulation software Analysis of Microelectronic and Photonic Structures (wx-AMPS). And the conversion efficiency of the cell is investigated with thickness of p-type layer, intrinsic layer and n-type layer with proper band gap of each material and doping concentration. The thickness of each layer is optimized for maximum efficiency. The work is done in two steps. Firstly, the influence of thickness of different layers has been analyzed for single junction in the efficiency of the amorphous silicon solar cell. Secondly, the influence of band-gap has been observed in the efficiency. Here, Amorphous silicon carbide (a-SiC:H) has chosen as window layer and hydrogenated amorphous silicon (a-Si:H) as absorber layer. Our results have shown a significant enhancement in conversion efficiency of 17.74% for single junction.*

Keywords: Absorber Layer, Amorphous Silicon, Band Gap,Efficiency, Single Junction.

1. INTRODUCTION

Now a day, thin film silicon technology has become one of the most promising branches in photovoltaic industry. The main reason of utilization of thin-films instead of high-purity bulk materials is to reduce production costs. Various thin film materials like copper indium gallium di-selenide (CIGS), cadmium telluride (CdTe), and dye-sensitized nano-crystalline titanium dioxide (nc-TiO) are under research. Among other thin films amorphous silicon is most attractive material because of material availability, low cost, non-toxic, easy fabrication and large-scale deposition relatively low temperature so that low cost materials like glass can be used as substrate. Bandgap variation is most attractive feature for amorphous silicon solar cells. Band gap of amorphous silicon materials can be varied within large range by adding hydrogen, oxygen, carbon and germanium because bandgap is varied according to percentage of materials (hydrogen, oxygen, carbon, germanium) into the amorphous silicon alloys.

Cell performance depends on various parameters such as bandgap of materials used, thickness of each layer specially absorber layer, donor and acceptor concentration, defect density etc. Open circuit voltage, short circuit current, fill factor, efficiency is required to determine overall performance of the cell. Single junction cannot provide higher efficiency because it uses little portion of sun spectrum according to absorber layer bandgap. To overcome this limitation of the leakage of maximum energy utilization of sunlight multijunction solar cells, based on the spectral splitting principle have been devised so that the maximum energy can be absorbed. Because multijunction solar cell with different band gap of absorber layer is used to capture the maximum portion of the sun spectrum. Tandem cell which uses maximum sun spectrum gives better efficiency than single junction solar cell. Because of having narrow bandgap, hydrogenated amorphous silicon (a-Si:H) and amorphous silicon germanium (a-SiGe:H) alloys is widely used as intrinsic layer for amorphous silicon based tandem solar cell [1].

The Tandem solar cells have good stability than single junction solar cells in respect to effect of light soaking. For Tandem (double junction) using a-Si1-xGex materials light soaking effect is 18% which is reduced from 30% in single junction a-Si solar cells [2].

Efficiency improvement of tandem solar cell mostly depends on designing and fabricating a good tunnel recombination junction. Top and bottom cells are connected to each other through tunnel recombination junction. It is the area where the electrons and holes recombine from top cell and bottom cell respectively [3]. Cell performance will degrade if the recombination process has not done properly as accumulated charges will interrupt the electric field inside the cell [4][5]. Tunnel junction (recombination layer) is used between two cells to maintain the current flow through cell.In this paper, we analysis a single junction solar cell with the structure ITO/a-SiC:H/a-Si:H/a-Si:H/ZnO/Ag.

2. MATERIALS DETAIL

Materials has used for this simulation and process has used for simulation the cell is discussed detail in this section.

Amorphous silicon is tetrahedrally bonded to four neighboring silicon atoms, but it does not form a continuous crystalline lattice as in crystalline silicon. a-Si:H does not exhibit a structural order over a long range. Though a-Si:H lacks the long-range order, it has the same short-range order as single crystal silicon. The small deviations in bonding angles and bonding lengths between the neighboring atoms in a- Si:H lead to a complete loss of the locally ordered structure on a scale exceeding a few atomic distances. The resulting atomic structure of a-Si:H is called a continuous random network [6]. Atomic structure of silicon and amorphous silicon is shown in Fig. 1.

The larger deviations in bonding angles and bonding lengths between the neighboring atoms in a-Si:H result in so-called weak or strained bonds. Weak bonds can easily be broken when enough energy is available. This process leads to the formation of defects in the atomic network. In a crystal, any atom that is out of place in a lattice forms a defect.

In a-Si:H, defects are mainly silicon atoms that are covalently bonded to only three silicon atoms (threefold coordinated) and have one unpaired electron, a so-called dangling bond [7]. Another defect configuration is a silicon atom bonded to five silicon atoms (fivefold coordinated) [8]. This configuration is referred to as a floating bond [6]. Defects in amorphous silicon is shown in Fig. 1.

In pure a-Si, there is a large concentration of about 10^{21} defects per cm^3 in the amorphous atomic structure. This defect can be solved by introducing hydrogen into the silicon. It then becomes hydrogenated amorphous silicon. Hydrogen passivation of dangling bond defects reduces the defect density from about 10^{21} cm^{-3} in pure a-Si to 10^{15}–10^{16} cm^{-3} in a-Si:H [6].

Band gap of amorphous silicon materials can be varied within large range by adding hydrogen, oxygen, carbon and germanium because bandgap is varied according to percentage of materials (hydrogen, oxygen, carbon, germanium) into the amorphous silicon alloys.

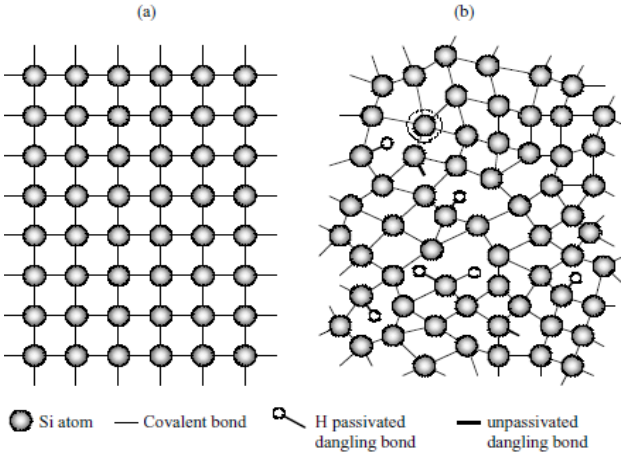

Fig. 1: Schematic representation of the atomic structure of (a) single crystal silicon, (b) hydrogenated amorphous silicon [6].

Because of having narrow bandgap, hydrogenated amorphous silicon (a-Si:H) and amorphous silicon germanium (a-SiGe:H) alloys is widely used as intrinsic layer for amorphous silicon based tandem solar cell. Cell performance depends on both thickness and bandgap of absorber materials of cells. Bandgap has been varied by different a-Si alloys a-$Si_{1-X}C_X$:H, a-$Si_{1-X}Ge_X$:H, aSi:H.

These alloys band gap properties can be changed by changing the ratio of these alloys. These alloys were used in the cell structure in different ways in different layers for acceptable performance.

The p-i-n structure of a-Si solar cells has been deposited on stainless steel substrate coated with a ITO [9]. The ITO forms the top electrode and zinc oxide with silver has been used as the bottom electrode. Since only the a-Si:H intrinsic layer contributes to the current generation, the optimal optical design of the cell structure maximizes absorption in the intrinsic layer and minimizes absorption in all the other layers. p and n layers has been used for creation of electric field and this electrical field is used for separation of created electrons and holes in the intrinsic layer to achieve the PV effect.

The textured ITO (Indium Tin Oxide) use for rough interfaces into a solar cell [10]. When light enters the solar cell, and reaches a rough interface, a part of it will be scattered in various directions instead of propagating in the specular direction. In this way, the average light path in a layer is increased and the light absorption is enhanced. ITO is highly transparent good electrical conductor, shows physical stability and chemically inert properties. Silver (Ag) is used for its low resistivity to reduce the reflection losses through all layers. ZnO layer is applied between n-layer and Ag to increase the JSC [11]. A key advantage of ZnO/Ag is that it put the end of the adhesion problem between a-Si and metal contact. So, ZnO–Ag has been chosen as the back contact of the solar cells.

3. SIMULATION TOOL WXAMPS

wxAMPS is a substantially new solar cell simulator for modeling one-dimensional devices composed of various materials. It accepts the same input parameters as AMPS, conforms to similar physical principles and numerical descriptions of defects and recombination and adds the effects of tunneling currents based on two different tunneling models. wxAMPS is written in C++ and includes a number of revisions to the basic algorithm. Across-platform C++ library, wxWidgets, is used to develop a new graphical user interface (GUI) to allow quick data entry and enhanced visualization of results for comparison and analysis [12].

The main user interface (Fig. 2) is almost the same as the version described previously with the exception of a “Settings” section under the Run button, allowing users to switch the tunneling models and adjust numerical parameters. In the “Settings” dialog box, users can set up upper limit of iteration times, the convergence precision and the clamping range that is the maximum variables change in one iteration. The variables variation is clamped in order to avoid the overestimation generated by the Newton method [13].

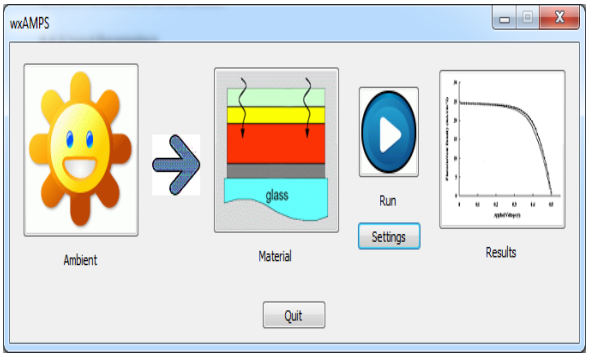

Fig. 2: Main user interface of wxAMPS [14]

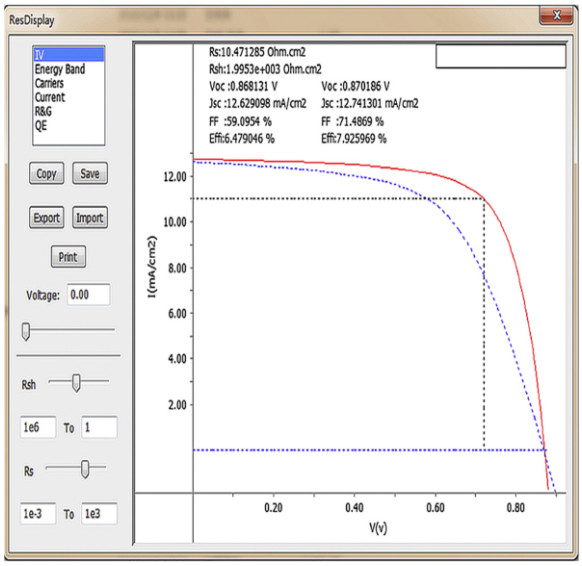

Fig. 3: Display dialog box for simulation results and analysis [15].

Another improvement is in the ambient dialog box where the bias voltages of interest can be loaded from a user customized text file. The ambient conditions configured previously by the user are cached automatically to help reduce the time spent tweaking the simulation environment [13].

Two additional slide bars have been added to the results dialog box in order to allow users to modify the values of the series and shunt resistances (Fig. 3). Upon adjustment of the slide bars, a new current-voltage curve is calculated and displayed and new device parameters are obtained. The revised results and the new curve are updated simultaneously when changing the slide bars of the shunt and series resistances [13].

4. DESIGN PARAMETERS AND SIMULATION PROCESS

Proper control of parameters of each layers of a pin structure single junction solar cell needs to produce highest efficiency. An unintentional change of any value of these layers may cause an undesirable change in the solar cell current-voltage curve (I-V characteristic curve) and quantum efficiency. Sometimes results are very difficult to understand Table 1 shows the Electrical Parameters information and Table 2 shows Contact Parameters.

The values of different design parameters have been adopted from some standard references [16]. The values of back contact parameters, front contact parameters and general layer parameters used in simulation to solve for the set of transport equations and boundary conditions are given in Tables 1 and 2. Temperature is set to room temperature at 300K.

Table 1: Electrical Parameters information

Parameters	**P (a-SiC:H)**	**I (a-Si:H)**	**N (a-Si:H)**
Relative Permittivity εr	11.90	11.90	11.90
Band gap (eV)	1.85-2.2	1.6-2.0	1.6-1.8
Electron Affinity (eV)	3.7	3.8	3.80
Effective density of states in conduction band (cm-3)	2.5e20	2.5e20	2.5e20
Effective density of states in valance band (cm-3)	2.5e20	2.5e20	2.5e20
Electron mobility,μn (cm2/v-s)	10	20	20
Hole mobility,μp (cm2/v-s)	1	2	2
Donor concentration (cm-3)	0	0	8e18
Acceptor concentration (cm-3)	3e18	0	0

Table 2: Contact Parameters

Parameters	Front Contact	Back Contact
Barrier height, (φbo/ φbL)	PHIBO = 1.9 eV	PHIBL = 0.3 eV
Electron recombination speed	SNO = 1x107 cm/s	SLN = 1x107 cm/s
Hole recombination speed	SPO = 1x107 cm/s	SPL = 1x107 cm/s
Reflection coefficient	RF = 0.1	RB = 0.9

Simulation has done for optimization of cell parameters for getting maximum efficiency and better cell performance. For optimizing process bandgap has optimized first and thickness has optimized later. Simulation process has started for single cell. After optimization of single cell then double cells has been optimized. For simulation p-i-n structure has used. I layer (intrinsic layer) has used as absorber layer. Absorber layer used to absorb photonic energy from sunlight to create electron and hole pair. P and N layer has used for creation of electric field for separation of generated electron and hole pairs in the intrinsic layer.

In optimization process, cell (ITO/aSiC:H/aSi:H/ aSi:H/ ZnO/Ag) has optimized both for bandgap and thickness.

5. RESULT AND DISCUSSIONS

5.1 Optimization of Cell

Structure of single junction is shown in Fig. 4. In Fig. 4 it represents that a-SiC:H has been used as p-layer or window layer, a-Si:H has been used as i-layer and also used as n-layer.

In order to optimize the p-layer of first cell simulation has been done in wx-AMPS with keeping all parameters at constant as in Table 1. The simulation results obtained as shown in Fig. 5, where efficiency of cells has been increased with the increment of thickness of p-layer. But after certain thickness of p-layer efficiency of the cells has started to decrease. Maximum efficiency was found 17.6899% at 20 nm thickness and at 1.95 eV bandgap for p-layer.

In order to optimize the i-layer simulation has been done in wx-AMPS with keeping all parameters according to the values of for intrinsic a-Si:H material as in Table 1 and Table 2. The obtained simulation results have shown in Fig. 6. From the Fig 6, it is seen that maximum efficiency 17.6899% was found at 830 nm thickness and at 1.90 eV bandgap of i-layer.

Figure 7 shows efficiency versus thickness for n-layer. The n-layer thickness was optimized at 30 nm with efficiency 17.7483% although the curve shows higher efficiency at lower thickness but the current density decreases with decrement of thickness.

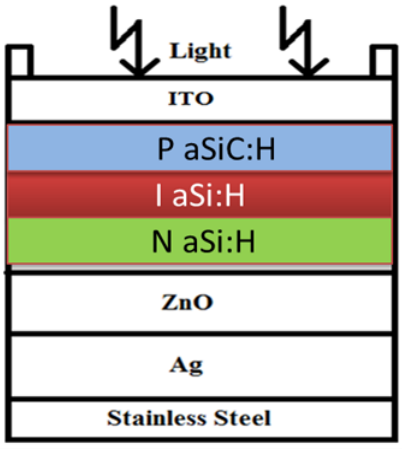

Fig. 4: Structure used as first cell.

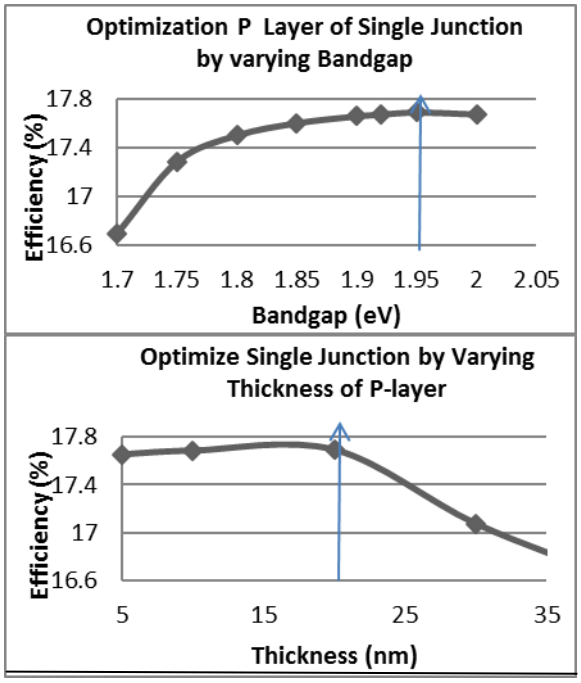

Fig. 5: Efficiency versus thickness, bandgap of single junction solar cells for p-layer.

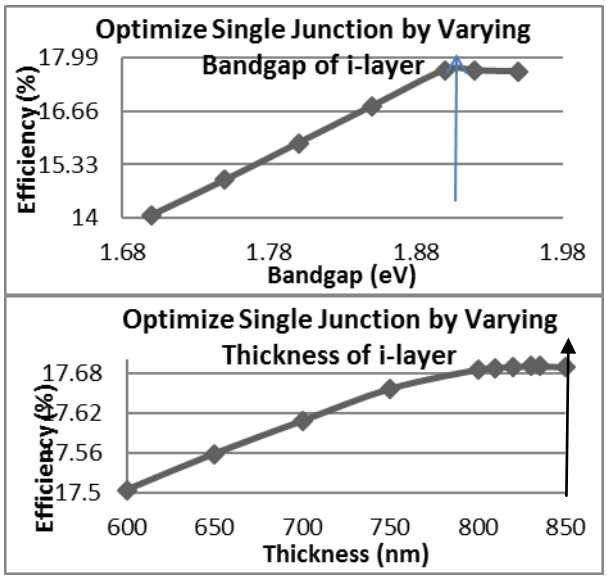

Fig. 6: Efficiency versus Thickness and Bandgap of single junction solar cells for i-layer.

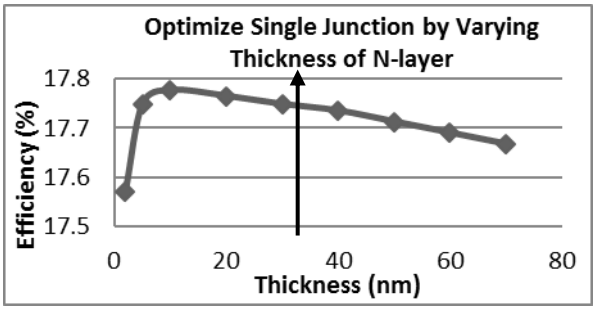

Fig. 7: Efficiency versus Thickness of single junction solar cell for n-layer.

Figure 8 represents obtained curve for all the characteristics parameters open circuit voltage (Voc), short circuit current (Jsc), fill factor (FF) and efficiency (η) of first cell for finding an optimized cell. According to fig. 8 it has seen that open circuit voltage is almost same with varying thickness of absorber layer while fill factor is decreasing. But short circuit current is increasing with thickness of absorber layer which has good effect on increment of efficiency with change of thickness of absorber layer. Black arrow shown in fig. 8 indicates the point at which the maximum efficiency found. Table 3 shows the summary of single junction first cell at highest efficiency.

So, 20 nm, 830 nm, 30 nm are the optimized thickness value for p-layer, i-layer and n-layer, respectively and the highest efficiency is found 17.7483%.

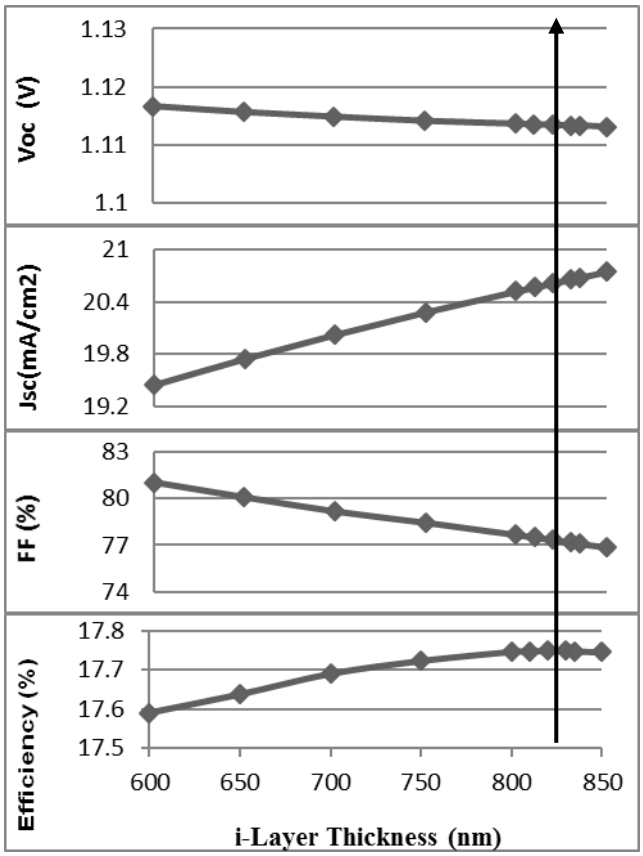

Figure 8: Performance parameters at highest efficiency.

Table 3: Summary at highest efficiency

P (Bg: 1.95) (nm)	I (Bg: 1.9) (nm)	N (Bg: 1.9) (nm)	Voc (V)	Jsc (mA/cm^2)	Fill Factor (%)	Efficiency (%)
20	830	30	1.113	20.657	77.178	17.7483

7. CONCLUSION

Amorphous silicon is most important material for solar cell because its material availability, low cost, large scale deposition at relatively low temperature. Bandgap Engineering is most attractive feature for amorphous silicon materials. As it is nontoxic material, it has less or almost no harmful effect on environment. According to simulation result by varying both bandgap and thickness, single junction amorphous silicon solar cell has good conversion efficiency. Single junction absorbs part of solar spectrum while double or triple junction may use more solar spectrum than single junction. Hope, it will be done in future.

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