Short Communication

Performance of *p-i-n* Hydrogenated Amorphous Silicon Thin Film Solar Cells Device

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We have fabricated the *p-i-n* hydrogenated amorphous silicon (*a*-Si:H) thin films by glow discharge technique using silane (H_2 diluted) at corning 7059 glass substrate (5×5 mm^2) coated with indium tin oxide (ITO) in a single chamber reactor at plasma excitation frequency 13.56 MHz. The deposition parameter was: temperature depositions at 200 °C, pressure at 75-100 mTorr, power 40-50 W, power density 2-2.5 W/m^2, doping ratio of 0.25-1 % and deposition rate 4-6 Å/s. The thickness of the *p-i-n a*-Si:H layers was varied between 530 to 560 nm. The thickness of *p*-layer was varied between 10 to 40 nm, *i*-layer and *n*-layer constant at a thickness of 500 nm and 20 nm. As a back contact, we used aluminum by the sputtering technique and ITO layer will act as the front contact of the cell. The solar cells were I-V characterized under the dark state (without illumination) and AM 1.5 (illumination mW/cm^2) by the solar simulator. The device produced in the dark state has shown the presence of a current with a magnitude in the order of 10^{-3} A. The maximum energy conversion efficiency in this study was 4.6 % and fill factor 0.40.

Keywords: Hydrogenated amorphous silicon, Single junction, PECVD, Efficiency.

1. INTRODUCTION

Silicon (Si) is a raw material ideally suitable to the production of renewable energy by photovoltaic (PV). For this reason, silicon is a very abundant material which has benefited from numerous developments to the bulk crystalline silicon solar cells. Up to now, most commercial solar cells are expensive.

Today, several fabrication techniques thin film solar cells, PECVD, hot-wire CVD, photo CVD and sputtering have been applied for improving cell performance [1, 2]. PECVD is the most successful technique for the fabrication of *a*-Si:H thin film solar cells. Thin film hydrogenated amorphous silicon is predominantly deposited using plasma enhanced chemical vapor deposition (PECVD) technique which control microstructure, hydrogen and doping of the layer.

This makes it a based material for single junction cells. 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 single junction thin-film solar cells has gradually been developed from 2.4 % to 10.1 % [3].

One of the strategies to improve the efficiency of the solar cell is to improve the open-circuit voltage (V_{OC}). The open-circuit voltage of the *p-i-n* solar cell is among its most important device parameters [4]. Simulation studies also were obtained the energy conversion efficiency of 4-5 % when a *i*-layers a constant up 450 nm [5]. The effciency of solar cell is the resultant outcome of its open circuit voltage (V_{oc}), short circuit current (J_{sc}), and fill factor (FF). For improving the effciency of a solar cell, it is necessary to upgrade the above-mentioned parameters such as *p* and *i* layer thickness. In order to improve the device performance

of *a*-Si:H solar cells, emphasis should be given mainly on higher short circuit current (J_{sc}) by developing light trapping scheme [6].

A new device structure has been introduced by using hydrogenated microcrystalline silicon (*μc*-Si:H) as an active layer for solar cells in 1994 by the IMT group at the University of Neuchatel in Switzerland. They achieved an initial effciency of 4.6 % for a *μc*-Si:H *p-i-n* single-junction solar cell with almost no light-induced degradation.

The record *a*-Si:H single junction module on 1.43 m^2 with a 9.1 % have been fabricated by Salabas [7] from TEL Solar AG in Switzerland. Now hydrogenated amorphous silicon solar modules have entered to the market for power generation applications.

In this paper, we present measurement results on the *I-V* parameters of single-junction *a*-Si:H *p-i-n* solar cells. The solar cell performance in this paper was measure by using the solar simulator under AM 1.5 (illumination mW/ cm^2) having an active area of 0.25 cm^2, and in the dark state (without illumination).

The aim of this paper is to investigate the conversion efficiency in an *a*-Si:H *p-i-n* single junction solar cell. The *p-i-n a*-Si:H single junction thin film solar cells have been fabricated by using PECVD method in a multiplasma-monochamber reactor [8].

2. EXPERIMENTAL

2.1 Fabrication of *p-i-n a*-Si:H Thin Films

The role of plasma *a*-Si:H is to provide a source of energy to dissociate the SiH_4 molecules. The energy transferred to the SiH_4 (silane) molecules in the collisions with electrons is radiated as visible light, thus the deposition method is called as the glow discharge at typical deposition rates of 4-6 Å/s. Fig. 1

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shows the schematic representation of PECVD deposition system in a multiplasma-monochamber reactor [4].
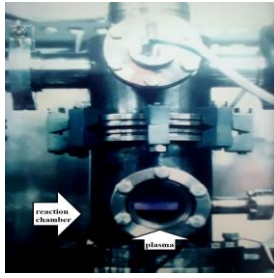

Fig. 1 – The PECVD deposition chamber

The deposition parameters of the *a*-Si:H based *p-i-n* layers were temperature deposition = 200 °C, pressure = 75-100 mTorr, power 40-50 Watt, power density 2-2.5 Watt/m^2, doping ratio phosphine (PH$_3$) or diborone (B$_2$H$_6$) of 0.25-1 % and electrode distance of 2 cm. The non dope (*i* layer) and doped layers (*p* and *n* layers) have been deposited from decomposition of SiH$_4$ using 13.65 MHz (electrical discharge) PECVD single chamber reactor. The thickness of the *p-i-n a*-Si:H layers was varied between 530 to 560 nm.

The cells with an area of 5×5 mm^2 have been fabricated on top of the ITO coated corning 7059 glass substrates. The structure of the fabricated cells is corning 7059 glass/ITO/*p-a*-Si:H (10-40 nm)/*i-a*-Si:H silicon (500 nm)/*n-a*-Si:H (200 nm)/Ag (100 nm)/Ag (100 nm), which is shown schematic representations of the *p-i-n a*-Si:H solar cell in (see Fig. 2).
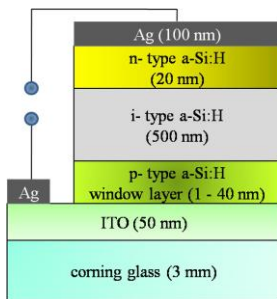

Fig. 2 – Structure of the *p-i-n a*-Si:H solar cell device

2.2 I-V Characterization of p-i-n a-Si:H device

Tabel 1 show that we have been fabricated in four types a single junction *a*-Si:H solar cells having an active area of 0.25 cm^2 which is called as cell-1 (*p*-layer = 10 nm, *i*-layer 500 nm and *n*-layer 20 nm), cell-2 (*p*-layer = 20 nm, *i*-layer 500 nm and *n*-layer 20 nm), cell-3 (*p*-layer = 30 nm, *i*-layer 500 nm and *n*-layer 20 nm) and cell-4 (*p*-layer = 40 nm, *i*-layer 500 nm and *n*-layer 20 nm).

Table 1 – Identification of *a*-Si:H solar cell fabrication

sample	*p-i-n* thickness (nm)	gas concentration (sccm)
Cell-1	10 – 500 - 20	0.25 – 100 – 0.25
Cell-2	20 – 500 – 20	1 – 100 – 1
Cell-3	30 – 500 – 20	1 – 100 – 1
Cell-4	40 – 500 – 20	1 – 100 – 1

The curent-voltage (IV) characteristics of 0.25 cm^2 single junction solar *p-i-n a*-Si:H cells have been measured with in the dark state and under AM 1.5 illumination. A double source sun simulator have been used from Wacom (WXS 140S super) at standard test conditions 25 °C, AM1.5G spectrum, 1000 W/m2. For these devices, Ag (100 nm) as a back contact were used. The performance of solar cell devices that have been fabricated are charactrized using solar silmulator. Maximum power is delivered to the load when its impedance matches that of illuminated device. The solar conversion efficiency is given by $\eta = V_{oc}.I_{sc}FF / P$, where V_{oc} is the open circuit voltage (the voltage generated when the load resistance is infinite), Isc is the short circuit current (the current generated when the load resistance is zero) and FF is the fill-factor (defined to be the ratio of the maximum power generated by the cell divided by V_{oc}/I_{sc}) and the power of radiation incident P is 963 W/m^2 [5].

3. RESULT AND DISCUSSIONS

Fig. 3 shows that the dark *I-V* curve shifts towards the right side (i.e. the dark current decreases for a given voltage), as the *p*-layer thickness increases from 10 to 40 nm. Above 10 nm up to 30 nm, the current density under dark condition, Id does not change appreciably. It would be the dominant mechanism behind the generation of Id is thought to be the recombination at the *p-i* interface layer.
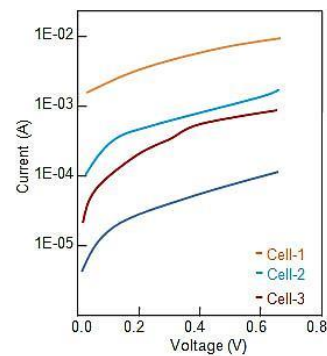

Fig. 3 – Dark *I-V* characteristics of the *p-i-n a*-Si:H

The same layer thickness as the doping ratio of 1 % the output current in the order of 10^{-3} to 10^{-4} A. With the increase of doping the output current decreases, this is caused by the amount of doping gas in the window layer penetrating into *i*-layer, which is active layer. The thickness of *p-i-n* layer 570 nm its output current is in order 10^{-5} to 10^{-} A, this is because it is too thick in *n*-layer.

Fig. 4 shows the values of J_{sc}, V_{oc} FF and efficiency versus the thickness of *i*-layer *a*-Si:H cells and the conversion efficiency is calculated based on these parameters. The absorbance of solar radiation in each layer is depending on the thickness of each layer, particularly in the active *i*-layer of cell. Because the photons absorbed in *i*-layer contributes to the current generation. The dependence of the integrated absorbance and conversion efficiency of a single junction *p-i-n* type solar cell with respect to the thickness of *p*-layer (10 nm) as shown in Fig. 4, as a

result, absorbance and conversion efficiency increases with respect to the thickness of *p*-layer. But, the recombination and trapping processes involved in *a*-Si:H is not considered into an account.
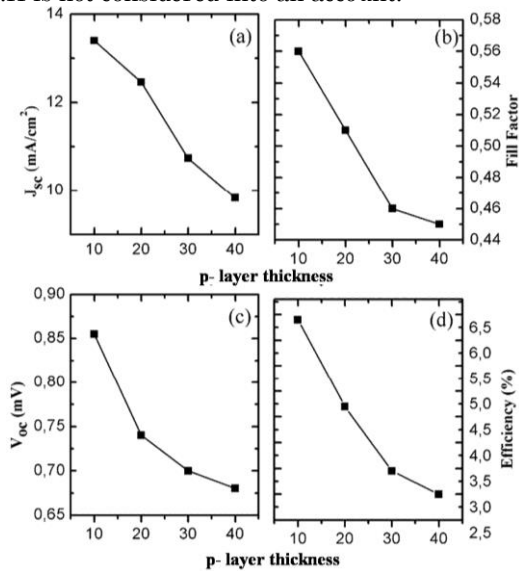

Fig. 4 – Values of J_{sc}, fill factor, V_{oc} and efficiency versus the thickness of *i*-layer *a*-Si:H cells

However, it is reasonably well established that the recombination processes come to be important in i-layer of thicknesses greater than the depletion width of a cell. To minimised the effect of recombination and trapping of charge carriers, the width of *i*-layer shouldn't exceed the width of the depletion layer. *I-V* characteristics of the single junction *p-i-n* solar cell are shown in Fig 5. By using a double source sun simulator, which gives current (*I*) and voltage (*V*) characteristic parameter values, and by using the equation conversion efficiency is calculated.

Tabel 2 show the optimum conversion with 530 nm layers thickness is *p*-layer = 100 nm, *i*-layer = 500 nm and *p*-layer = 200 nm with doping concentration 25 % sccm. As for the same thickness with an increased doping concentration of 1 % sccm the decrease of efficiency is 4.2 % as well as if the layer thickness *p-i-n* increases.

Table 2 – *I-V* measurement of *a*-Si:H solar cells

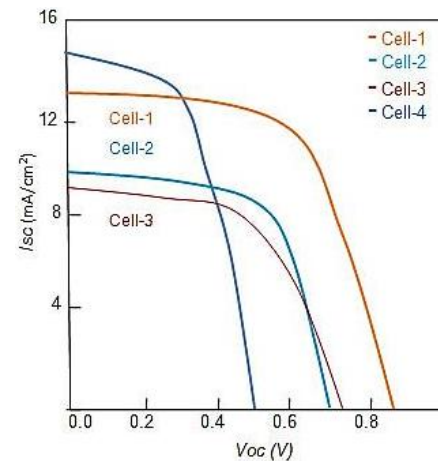| sample	V_{oc}	I_{sc}	V_m	I_m	FF	η
Cell-1	0.86	13.40	0.60	7.65	0.40	4.6
Cell-2	0.70	10.74	0.55	7.66	0.56	4.2
Cell-3	0.52	15	0.33	10.40	0.44	3.4
Cell-4	0.74	9.30	0.62	5.36	0.48	3.3

Fig. 5 – *I-V* characteristics of the *p-i-n a*-Si:H cells (AM 1.5)

Here, integrated absorbance and conversion efficiency depend on the thickness of i-layer. The absorbance of *p*-layer is optimised for optimal photovoltaic performance.

From the plotted *I-V* curve with the thickness of p-layer 10 nm based on the best cell. Here, the optimum conversion efficiency in this work is 4.6 % is low compared to the present highest conversion efficiency (9.1 %) [7]. Thickness of the interface recombination region determining the recombination component of is ~ 30-50 nm for the present solar cells.

Since there is 7 % increase in the open circuit voltage by the introduction of a suitable *p*-layer, then even with a 4-5 % reduction in fill factor, the energy conversion efficiency of the other cells will be increased by ~ 3-5 %.

4. CONCLUSIONS

The single-junction *p-i-n a*-Si:H solar cell has been fabricated by PECVD. We report an *a*-Si:H single junction cell on 0.25 cm² with a 4.6 % conversion efficiency for *p*-layer, *i*-layer and *n*-layer thickness of 10, 500 and nm after characterizing under AM 1.5 illumination.

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