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Application of a-Si:H in p-i-n Solar Cell by VHF-PECVD Method

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Abstract

The a-Si:H p-i-n solar cells have been deposited on Corning glass coated with Transparent Conductive Oxide (TCO) by employing the VHF-PECVD method at the substrate temperature of 275 °C. The 10% SiH_4 gas diluted in H_2 was used as a gas source and the doping process was done by gas admixture of B_2H_6 and PH_3 for p- and n-layer respectively. A careful mono-layer optimization such as power discharge and deposition pressure was done to obtain the best a-Si:H film quality. The deposition rate (r_d), optical bandgap (E_{opt}), and photoconductivity (σ_{ph}) of i-layer was obtained are 2.04 Å/s, 1.69 eV, and 9.23 x 10^{-5} S/cm, respectively. Two different solar cells were then fabricated by applying the active layer (i-layer) of 4400Å and 5500Å thickness, while the thicknesses of p- and n-layer were fixed to 150Å and 300Å respectively. The current-voltage measurement under 34 mW/cm^2 light illumination shows higher value of V_{OC}, I_{SC}, and efficiency which are of 0.77 Volt, 15.92 mA/cm^2, and 9.39%, respectively for the solar cell with thicker i-layer of 5500Å.

Keywords: *VHF-PECVD, a-Si:H, active layer*

1. Introduction

Hydrogenated amorphous silicon (a-Si:H) and hydrogenated microcrystalline silicon (μc-Si:H) are commonly used for application in low-cost p-i-n thin film solar cells because of their low deposition energies. It can also be deposited at various substrates. These reasons have made the a-Si:H and μc-Si:H become potential for device technology with cheaper price. Research and development of a-Si:H based solar cell is now in a new stage aiming at mass production and cost reduction[1-3].

Plasma Enhanced Chemical Vapor Deposition (PECVD) nowadays is the most widespread industrial method for the production of a-Si:H. However, the growth of good quality of a-Si:H thin films requires generally three empirical conditions are fulfilled high dilution of silane (SiH_4) in hydrogen, high discharge power, and sufficiently high deposition temperature. These conditions still belong to the high energy deposition. Even though the uniform layer thickness is usually obtained under low deposition temperature, the resulted films by conventional PECVD method at 13.56 MHz of radio frequency still have low conductivity, low deposition rate, and high hydrogen content. To enhance the throughput of the PECVD process, a high deposition rate for the a-Si:H film is required. As known that the electrical and optical properties of a-Si:H are limited by its deposition rate[4]. An alternative method to overcome these problems is by introducing the 70 MHz of radio frequency which is known as Very High Frequency PECVD (VHF-PECVD). Some researchers have reported that the a-Si:H films which are obtained by VHF-PECVD method have relatively high deposition rate and low hydrogen content compared with conventional PECVD method. For solar cell application, the use of a-Si:H with low hydrogen content becomes even more important to obtain higher stability of solar cell performance[5-7].

The objective of this study is to investigate the a-Si:H films properties and their application to the p-i-n solar cells which have deposited using VHF-PECVD system in Laboratory for Physics of Electronic Materials, Institut Teknologi Bandung.

2. Experiments

The a-Si:H thin films were deposited using 10% SiH_4 gas diluted in H_2 as gas source by VHF-PECVD method. A careful optimization of the a-Si:H monolayer with rf power discharge and chamber pressure variation was carried out. All of these films were deposited at the substrate temperature of 275 °C on Corning 7059 glass. The optical bandgap and the thickness of film were determined using Ultra-Violet Visible (UV-Vis) measurement by Hewlett Packard 8452A Diode Array Spectrophotometer. The determination of optical bandgap was done by Tauc Plot method of the absorption coefficients that were obtained from the UV-Vis set data[8,9]. While, the thickness of film was calculated from the interference fringes of the UV-Vis transmission spectrum[10]. The two-probe method was used for conductivity measurement by Keithley 617. The photoconductivity was measured under 34mW/cm^2 intensity of light illumination.

Furthermore, the same deposition parameters which resulted the best quality a-Si:H material were used during solar cells fabrication. The doping process was done by gas admixture of B_2H_6 for p-layer and PH_3 for n-layer with 1% and 2% doping concentration, respectively. Two solar cells were fabricated by applying two different active layer (i-layer) thicknesses of 4400Å and 5500Å, while the thicknesses of p- and n-layer were fixed to 150Å and 300Å, respectively. All of the two solar cells were fabricated on the top of Corning glass coated with Transparent Conductive Oxide (TCO) based on the p-i-n structure as shown in Figure 1.

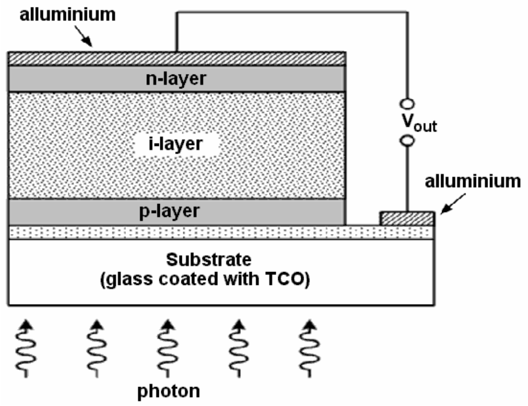

Figure 1. The structure of p-i-n solar cell

Table 1 shows the deposition parameters of the optimization of a-Si:H monolayer and Table 2 shows the parameters of p-i-n a-Si:H solar cells fabrication. The current-voltage (I-V) characteristic of solar cell was measured using Keithley 617 under 34mW/cm^2 intensity of light illumination.

3. Results and Discussions

Beside of the radio frequency as explained in section 1, in general there are other factors that influence the deposition process of a-Si:H thin film by Plasma Enhanced Chemical Vapor Deposition method. These factors, which are known as deposition parameters, are rf power and chamber pressure. The rf power plays an important role for gas source decomposition process. The gas source molecules were then decomposed to more simple radicals, while the chamber pressure determines the amount of radicals in chamber.

Table 1. Deposition parameters of the optimization of a-Si:H

Layer Type	**Gas Source**	**Gas Flow Rate (sccm)**	**Substrate Temperature (^{o}C)**	**RF Power (Watt)**	**Chamber Pressure (mTorr)**
p	$SiH_4 + B_2H_6$	70 + 0.7	275	8	300
				12	
				14	
i	SiH_4	70	275	6	300
				8	
				10	
				12.5	
				15	
		70	275	300	100
					300
					500
					700
n	$SiH_4 + PH_3$	70 + 0.7	275	8	300
				12	
				14	

Table 2. Fabrication parameters of p-i-n a-Si:H solar cells

Layer Type	**Gas Source**	**Gas Flow Rate (sccm)**	**Substrate Temperature (^{o}C)**	**RF Power (Watt)**	**Chamber Pressure (mTorr)**
p	$SiH_4 + B_2H_6$	70 + 0.7	275	12	300
i	SiH_4	70	275	8	300
n	$SiH_4 + PH_3$	70 + 0.7	275	8	300

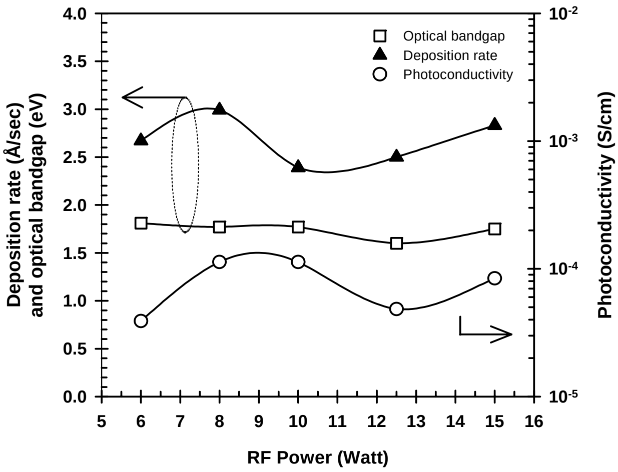

Figure 2. The characteristics of i-layers which resulted under optimization of rf power

In this research, both of these parameters have been optimized to obtain a best quality of a-Si:H thin film for solar cell application. Figure 2 shows the results of i-layer optimization by varying the rf power. It is clear that the deposition rate increases as the rf power increases from 6 to 8 Watt and also from 12.5 to 15 Watt, which is followed by increasing their photoconductivities. This indicates that the gas has been decomposed more effectively in the higher rf power. But the radical ionic bombardment caused the deposition rate decreased at 10 Watt of rf power. The best quality a-Si:H thin film was obtained at 8 Watt of rf power with highest deposition rate and photoconductivity of 2.99 Å/sec and 1.131 x 10^{-4} S/cm, respectively. The optical bandgap seems relatively constant at ~1.7 eV. Moreover, the chamber pressure was then optimized based on the result of rf power optimization.

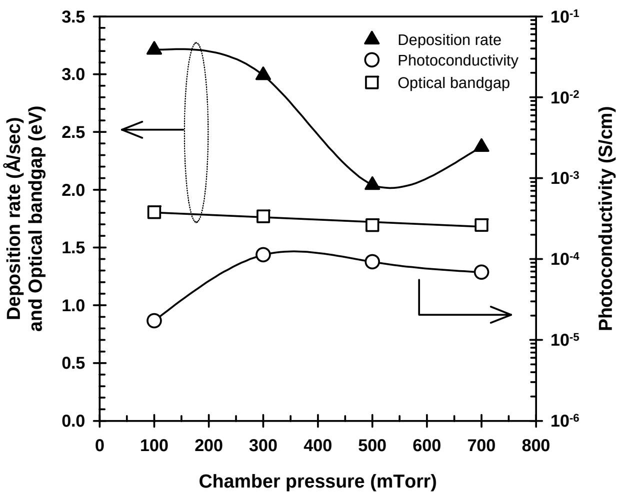

Figure 3. The characteristics of i-layers which resulted under optimization of chamber pressure

It is shown in figure 3 that the deposition rate decreases as the chamber pressure increases from 100 to 500 mTorr. The increasing of plasma radical concentration seemed the degradation of deposition reaction. However, the increasing of chamber pressure improved the structure of film, which was marked by its conductivity improvement. The best a-Si:H thin film was obtained at 300 mTorr with highest deposition rate and photoconductivity of 2,99 Å/sec and 1.131 x 10^{-4} S/cm, respectively, while their optical band-gap were relatively constant at ~1.7 eV.

Figure 4 shows the results for conductivity of p- and n-layer by varying the rf power. It is clear that the best quality p-layer was obtained at 12 Watt of rf power, with dark- and photo-conductivity of 7.78 x 10^{-11} S/cm and 4.01 x 10^{-5} S/cm, respectively. While, the best n-layer was obtained through 8 Watt of RF power, with dark conductivity and photoconductivity of 3.88 x 10^{-4} S/cm and 7.34 x 10^{-4} S/cm, respectively.

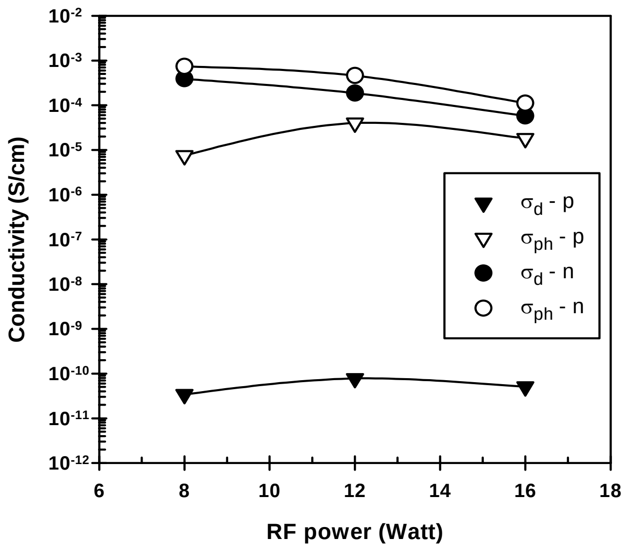

Figure 4. Conductivity of p- and n-layers under RF power discharge optimization: dark conductivity of p-layer (σ_d-p), photoconductivity of p-layer (σ_{ph}-p), dark conductivity of n-layer (σ_d-n), and photoconductivity of n-layer (σ_{ph}-n)

Furthermore, the best i-, p-, and n-layers were then applied to solar cell fabrication process. Two solar cells were fabricated by applying two different i-layer thicknesses of 4400Å and 5500Å. The thicknesses of p- and n-layer were fixed to 150Å and 300Å. Figure 5((A) and (B)) shows the current-voltage characteristic of the solar cells which were resulted from this study, while Figure 5(C) was resulted from previous study using conventional PECVD method.[11)] From this study, the best performance of open-circuit voltage (V_{OC}), short-circuit density current (J_{SC}), and efficiency having are of 0.77 Volt, 15.92 mA/cm^2, and 9.39%, respectively for the solar cell having thicker i-layer of 5500Å. We can see that the J_{SC} both of the solar cells which were resulted from this study higher than the previous study (J_{SC} = 6 mA/cm^2).

However, both of the solar cells from this study still show low fill factors compared to the solar cell from previous study. Those are caused probability by internal solar cell resistances such as high series resistance of inter-layers in the solar cell. We estimate that the high deposition rate of VHF-PECVD method leads to the bonding mismatch establishment of the solar cell inter-layers.

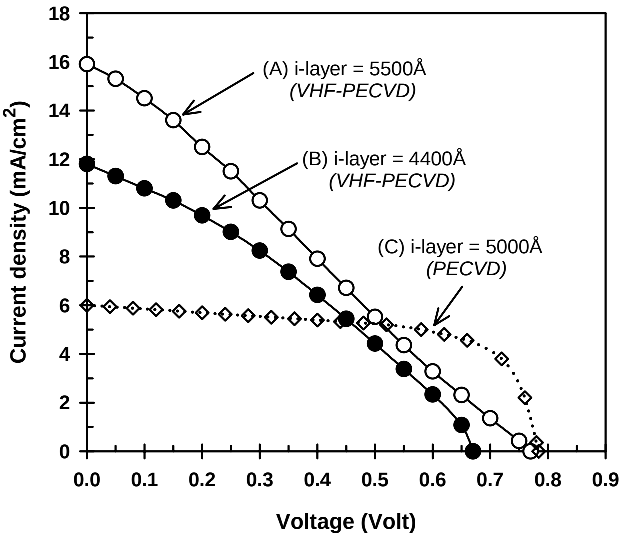

Figure 5. I-V characteristics of fabricated p-i-n a-Si:H solar cells which were resulted from this study using VHF-PECVD (A and B) and from previous study using PECVD (C)

4. Conclusion

Good quality of a-Si:H materials have been deposited by VHF-PECVD method with high deposition rate up to 2 Å/sec, as one of the needed condition for depositing the hydrogenated microcrystalline silicon (μc-Si:H) materials. This research also shows that the application of VHF-PECVD to solar cell fabrication result a good enough efficiency of ≈ 9%, which is the right direction for future solar cell development. However, the future researches of solar cell fabrication using VHF-PECVD method are needed to improve the fill factor of solar cell in order to enhance solar cell efficiency.

Acknowledgement

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