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High Deposition Rate of a-Si:H by Using Home Made VHF-PECVD Method and its Application to p-i-n Solar Cell

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Abstract: The a-Si:H p-i-n solar cells have been deposited on Corning 7059 glass coated with TCO by using the home made VHF-PECVD method. A careful monolayer optimization was done to obtain the best a-Si:H quality. The higher deposition rate of 3.21Å/s was obtained at 8W rf power in 100mTorr chamber pressure. The higher photoconductivity is 1.31×10^{-4} S/cm, with 1.77eV of optical bandgap, which was obtained at 8W of rf power in 300mTorr chamber pressure. The higher photoconductivity of p- and n-layer are 4.01×10^{-5} S/cm and

$7.34x10^{-4}$ S/cm respectively. These films were then applied for solar cells, with the active layer thickness of 4400Å to 6000Å while the p-layer and n-layer thickness fixed to 150Å and 300Å respectively. The current-voltage characteristic measurement under 34mW/cm^2 light illumination shows the higher V_{OC}, J_{SC}, FF, and efficiency which are of 0.77V, 15.92mA/cm^2, 0.26, and 9.39% respectively.

Keywords: VHF-PECVD, Optimization, a-Si:H, Active layer, Solar cell.

Introduction

It has been known that hydrogenated amorphous silicon (a-Si:H) and hydrogenated microcrystalline silicon (μc-Si:H) are commonly used for the application in low-cost p-i-n thin film solar cells because of its low deposition energy. It can also be deposited using various substrates. These reasons have made a-Si:H and μc-Si:H potential material 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]. Since the pioneering work of Spear and LeComber and Carlson and Wronski in the mid-seventies on doping of a-Si:H deposited through a radio-frequency (rf) discharge and its application for solar cells, extensive research and development efforts has been undertaken.

Generally, one of the major essential factors to enhance p-i-n a-Si:H solar cell performance is the active layer (i-layer) quality. Good quality a-Si:H thin films can be grown by conventional Plasma Enhanced Chemical Vapor Deposition (PECVD) method at 13,56 MHz rf. Using this method, low deposition temperature and uniform layer thickness are usually obtained, although the resulted films have low conductivity, low deposition rate, high hydrogen content, and more serious light-induced degradation due to the increase in SiH_2 bond density [4]. To enhance the throughput of the PECVD process, a high deposition rate for the a-Si:H film is required. An alternative method to overcome these problems is by introducing the 70MHz rf which is known as VHF-PECVD. The a-Si:H films obtained by VHF-PECVD method have a 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]. In this study, the a-Si:H p-i-n solar cells were deposited by using the home made VHF-PECVD method. The reactor system was designed with the gas inlet parallel to the substrate holder. The design will be compatible for the new Hot Wire Cell-VHF-PECVD method, by attaching the filament in gas inlet system as shown in Figure 1.

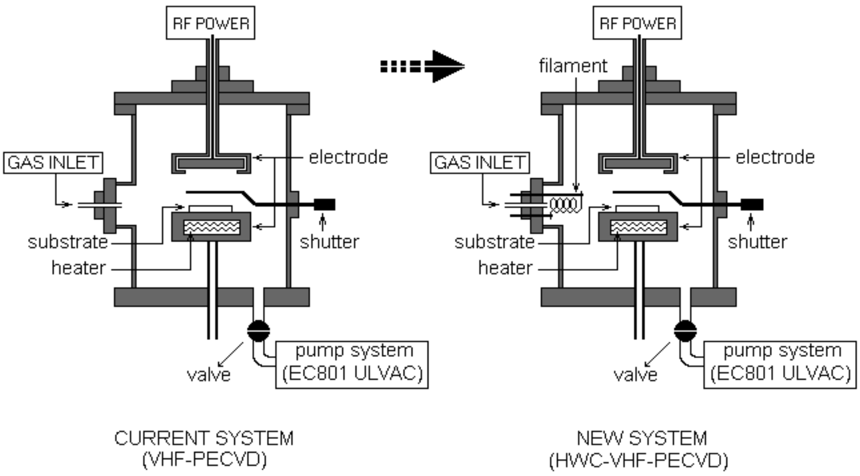

Figure 1. The home made VHF-PECVD reactor system: current system and new system.

Methods

The a-Si:H thin films were deposited using 10% SiH_4 gas diluted in H_2 as gas source at 275^oC substrate temperature on Corning 7059 glass. The optical band-gap and the thickness were determined by using the Ultra-Violet Visible (UV-Vis) measurement and the two point-probe method for conductivity measurements. The deposition parameters of monolayers optimization are shown in Table 1. Furthermore, the same parameters deposition of 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. The solar cells were fabricated on the top of Corning glass coated with TCO in ITO/p/i/n/Al structure by applying the i-layer of 4400Å to 6000Å thickness, while the thickness of p- and n-layer were

150Å and 300Å respectively. The current-voltage (I-V) characteristic of solar cell was measured under 34mW/cm^2 intensity of light illumination.

Table 1. Deposition parameters.

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	

Results

Besides 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 PECVD 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 into more simple radicals. While the chamber pressure determines the amount of radicals in chamber. In this research, both of these parameters have been optimized to get the 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 watts and also from 12.5 to 15 watts, which is followed by increasing their photo-conductivities. This indicates that the gas has been decomposed more effectively in the higher rf power. But the radical ionic bombardment caused the deposition rate to decrease at 10 Watts rf. The best quality a-Si:H thin film was obtained at 8W of rf power with highest photo-conductivity of $1{,}131 \times 10^{-4}$ S/cm, while the optical band-gap seems relatively constant at ~1,7eV.

In addition, the chamber pressure was then optimized based on the result of rf power optimization. It is shown in Figure 3 that the deposition rate decreases as the chamber pressure increases from 100 to 500m Torr. The increase radical concentration in plasma seemed to be caused by the degradation of deposition reaction. However, the increase in chamber pressure improved the structure of film, which was marked by its conductivity improvement. The best a-Si:H thin film was obtained at 300mTorr with higher deposition rate and photo-conductivity of 2,99Å/s and $1{,}131 \times 10^{-4}$ S/cm respectively. The optical band-gap was relatively constant at ~1,7eV. Figure 3 shows the results of p- and n-layers as the rf power varied. It is clear that the best quality p-layer was obtained at 12W of rf power, with dark- and photo-conductivity of 7.78×10^{-11} S/cm and 4.01×10^{-5} S/cm respectively, while, their optical band-gap were relatively constant at ~1,7 eV.

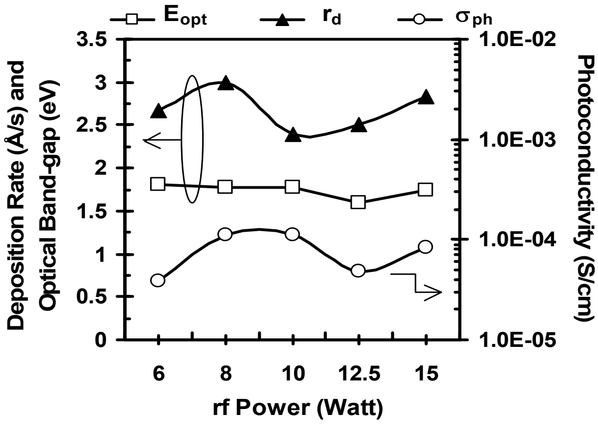

Figure 2. The characteristics of i-layers which resulted under optimization of rf power.

From both of optimization stage above, the higher deposition rate (r_d) of 3.21Å/s was obtained from 8W of rf power in 100m Torr of chamber pressure. It is comparable with the results reported by previous authors i.e. U. Kroll *et.al.* [8], R. Platz *et.al.* [9], and A. Lambertz *et.al.* [10].

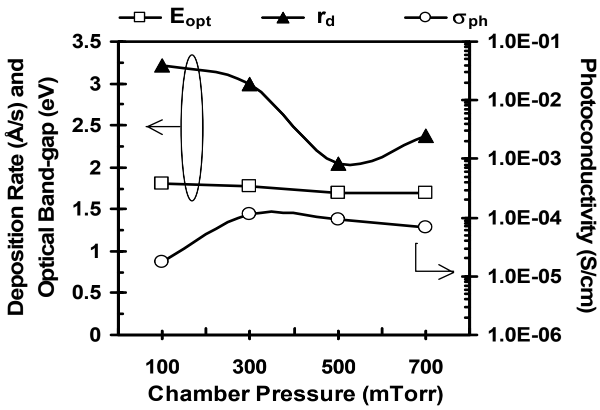

Figure 3. The characteristics of i-layers which resulted under optimization of chamber pressure.

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

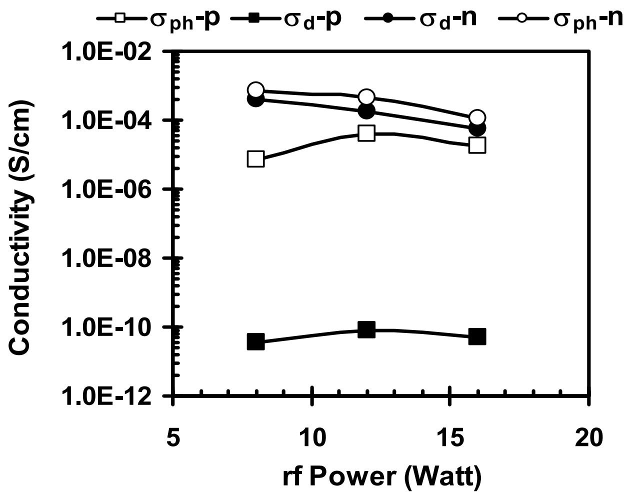

Figure 4. Conductivity of p- and n-layers under optimization of rf power.

Furthermore, the best i-, p-, and n-layers were then applied for solar cell fabrication by applying the i-layer of 4400Å to 6000Å thickness. The thickness of p- and n-layer were fixed to 150Å and 300Å.

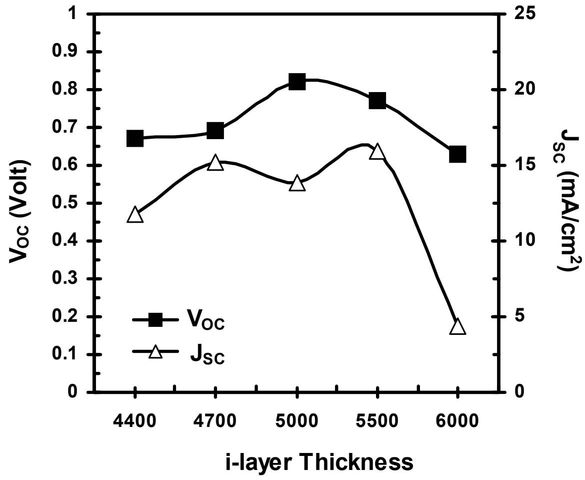

Figure 5. The solar cell characteristics which were obtained.

Figure 5 shows the characteristics of solar cells under 34mW/cm^2 intensity illumination. It can be seen that higher efficiency was obtained from solar cell with 5500Å i-layer thickness, which shows V_{OC}, J_{SC}, FF, and efficiency of 0.77V, 15.92mA/cm^2, 0.26, and 9.39% respectively. However, all of the solar cells still showed a low fill factor that is due to the high series resistance and low shunt resistance. The low fill factor is affected possibility by the defect state that occurs in interface layers. The other factor is affected by the imperfection of evaporation process for metal contact.

Conclusions

Good quality a-Si:H materials have been deposited by home made VHF-PECVD method with high deposition rate up to 3.21Å/s. As one of the necessary conditions for depositing the μc-Si:H materials, this will lead us to producing the μc-Si:H cells. This research also shows that the preliminary application of home made VHF-PECVD to solar cell fabrication can result in a fairly good efficiency of ≈9%, which is the right direction for future solar cell development. However, future work is needed to improve the fill factor of solar cell in order to enhance solar cell efficiency.

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