The Influence of Silane Gas Flow Rate on Optoelectronic Properties of μc-Si:H Prepared by HWC-VHF-PECVD Technique

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Abstract. Hydrogenated microcrystalline silicon (μc-Si:H) thin films have been deposited using 10% silane (SiH_4) in H_2 dilution by Hot Wire Cell Very High Frequency Plasma Enhanced Chemical Vapor Deposition (HWC-VHF-PECVD) technique. The resulted thin film characteristics were systematically studied as a function of the deposition parameter. The previous structural studies showed that the structural phase transition from amorphous to microcrystalline thin film was obtained using the filament temperature of 800 °C. In this study, the optoelectronic properties of μc-Si:H thin films were investigated as a function of the silane gas flow rate from 40 sccm to 80 sccm. The highest deposition rate of 3.6 Å/sec and the lower optical bandgap of 1.4 eV were obtained using 80 sccm and 60 sccm of the silane gas flow rate, respectively. The film showed the photosensitivity of 3 x 10^7, which is quite high above the minimal value of 10^3 for solar cell application.

Keywords: *HWC-VHF-PECVD technique; μc-Si:H; optoelectronic properties.*

1 Introduction

In actual application, the stability issues of thin film solar cells have forced the film thickness to small values in order to cut the carrier moving distance inside the bulk before being collected at the electrodes. A stacked-cell, known as multijunction solar cell, approach was developed where multiple thin cells of different band-gaps were stacked together, in order to compensate insufficient absorption of light in solar cells.

The hydrogenated microcrystalline silicon (μc-Si:H) was then employed as a stable and narrow-gap material in both single junction and multijunction solar cells. Extensive studies of μc-Si:H properties have been conducted due to highly complex microcrystalline structure forms, depending upon the deposition conditions [1, 2]. The knowledge of the microstructure of the devices in the transition region is remaining unknown. Great efforts have also been made to

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increase the growth rates of μc-Si:H by using new technique and exploring new plasma regimes. Among them, high-pressure conventional Plasma Enhanced Chemical Vapor Deposition (PECVD) using 13.56 MHz radio frequency (rf) in high power regime [3-5] and Very High Frequency PECVD (VHF PECVD) using 70 MHz rf [1,6-9] were the successful methods. For the cost-effective mass production of thin film silicon cells, it is essential to establish large area and high rate deposition technologies. Hence, the attention was therefore focused on the VHF-PECVD, due to the advantages of high plasma density and less ion bombardment. The VHF plasma is more suitable for high rate and high quality deposition than conventional PECVD. However, the shorter VHF wavelength lead to the disadvantage of inter-electrode voltage inhomogeneities in case of large area deposition [10].

Another technique has also been developed, namely the Hot Wire PECVD (HW-PECVD) technique. In the HW-PECVD technique, the source gases are decomposed effectively by both of 13.56 MHz rf power and a heated tungsten filament that placed above the substrate. Microcrystalline silicon thin films are commonly obtained using this HW-PECVD. However, high hydrogen content and low conductivity of the resulted thin film [11] were the disadvantages of the HW-PECVD technique besides the difficulty of control mechanism of substrate temperature under the effect of high filament temperature.

In order to overcome these problems, we have developed another technique named as the Hot Wire Cell VHF-PECVD (HWC-VHF-PECVD). Our previous study showed that μc-Si:H thin films were obtained using above 500 ^{o}C of the filament temperature [12]. Following this result, the investigation on the influence of silane (SiH_4) gas flow rate on the optoelectronic properties of μc-Si:H prepared was carried out and discussed here.

2 Experiments

The detail of our HWC-VHF-PECVD technique was described elsewhere [12]. An electrode system with capacitive coupling was used inside the chamber. A heated spiral tungsten filament was integrally placed inside the system of gas source inlet. The plasma gas was generated using the 70 MHz rf power. Figure 1 shows the schematic diagram of the HWC-VHF-PECVD chamber system.

The μc-Si:H thin films were deposited onto Corning 7059 glass substrates using 10% SiH_4 gas diluted in H_2 as the gas source. In order to investigate the influence of gas flow rate, the flow rate was varied from 40 sccm to 80 sccm. The used deposition parameters were 8 watts rf power, 275^{o}C substrate temperature, 100 mTorr chamber pressure, and 800^{o}C filament temperature.

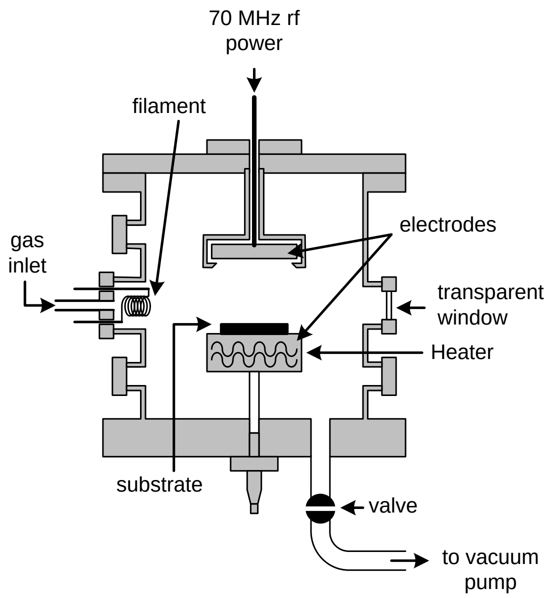

Figure 1 Schematic diagram of the HWC-VHF-PECVD chamber system.

The properties of resulted μc-Si:H thin films which are optical band-gap and the thickness were analyzed using the Ultra-Violet Visible (UV-Vis) spectroscopy, structure using the X-ray Diffraction (XRD) and Scanning Electron Microscope (SEM), and conductivity using Keithley 617 two-probe method.

3 Results and Discussion

The presence of the heated filament in gas inlet system was expected for gas decomposition mechanism. Therefore, the gas molecules that reach the electrode area have simple radical forms, and would then be decomposed again by the inter-electrode electrical field. The gas flow rate determined the staying time of the gas molecules inside the filament induction. The SiH_4 gas flow rate was then varied from 40 sccm to 80 sccm, while the other parameters were kept constant. Figure 2 and Figure 3 show the influence of the SiH_4 gas flow rate to the optoelectronic properties of the resulted silicon thin film. The deposition rate decreased from 2.3 Å/s to 1.9 Å/s as the SiH_4 gas flow rate increased from 40 sccm to 50 sccm which was followed by the decrease of its optical bandgap (see Figure 2) and conductivity (see Figure 3).

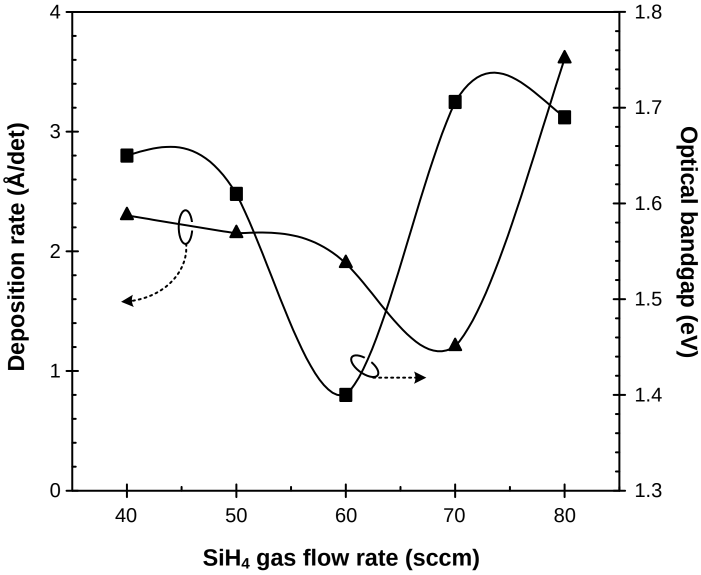

Figure 2 Deposition rate and optical bandgap characteristic of silicon thin films as a function of SiH_4 gas flow rate.

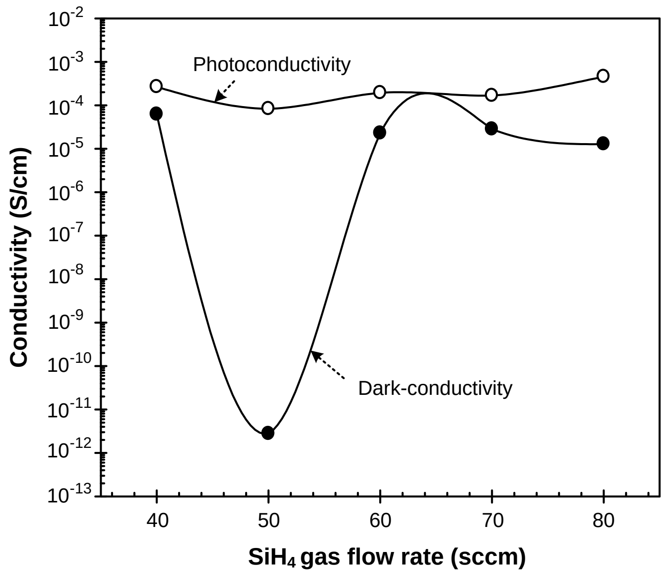

Figure 3 Conductivity characteristic of silicon thin films as a function of SiH_4 gas flow rate.

The conductivity of the films then increased as the SiH_4 gas flow rates increased from 50 sccm to 60 sccm, while its deposition rate and optical bandgaps remain decreased. This indicates that the SiH_4 gas flow rate of 50 sccm represents a transition deposition parameter to a good structure formation. The improved film structure using 60 sccm of SiH_4 gas flow rate was marked by its lowest optical bandgap of 1.4 eV followed by the increase of the conductivity value.

The use of the SiH_4 gas flow rate under 60 sccm seems more effective for the heated filament induction to decompose gas molecules, but the formed simple radicals may then coalesce with another simple radical to form a heavy molecule (e.g. Si_2H_6, Si_3H_9, etc.) before reaching the electrode area.

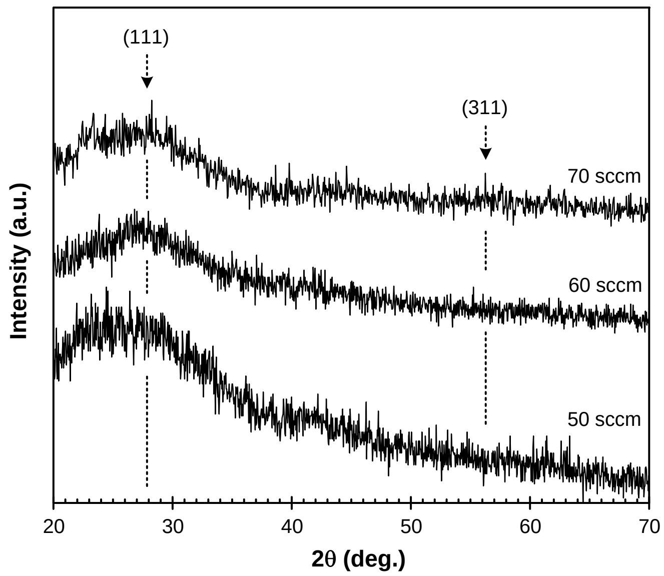

Figure 4 XRD spectrum of the silicon thin films deposited using various SiH_4 gas flow rate

As the gas flow rate increased, the heated filament did not have enough time to decompose the gas molecule. Therefore, the gas molecules reached the electrode area in un-decomposed forms. This was shown in Figure 2 that the optical bandgap again increased as the SiH_4 gas flow rates increased above 60 sccm. This indicates that the plasma was dominated by un-simple radicals (e.g. SiH_2 or SiH_3). However, the microcrystalline silicon structures were appear clearly at the SiH_4 gas flow rate of 70 sccm, as shown in Figure 4. The diffraction peaks of the microcrystalline structure were seen at the diffraction angles of ~28^o for (111) orientation and ~56^o for (311) orientation. The grain sizes of the microcrystalline structure were clearly shown by the surface profile of SEM measurement, in Figure 5.

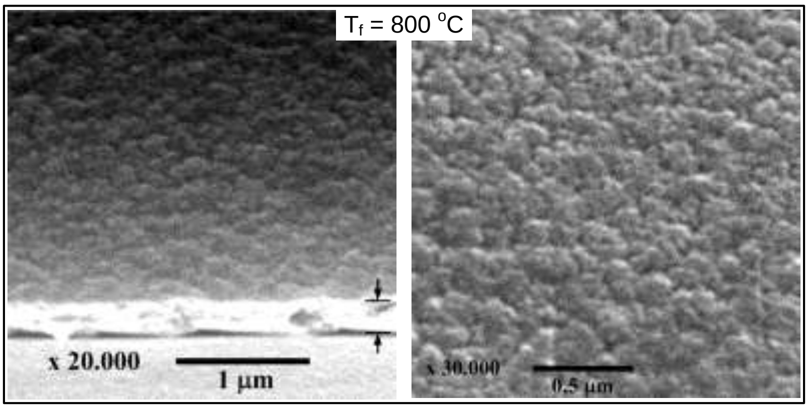

Figure 5 Surface profile by the SEM measurement of the µc-Si:H thin films deposited using the SiH_4 gas flow rate of 70 sccm.

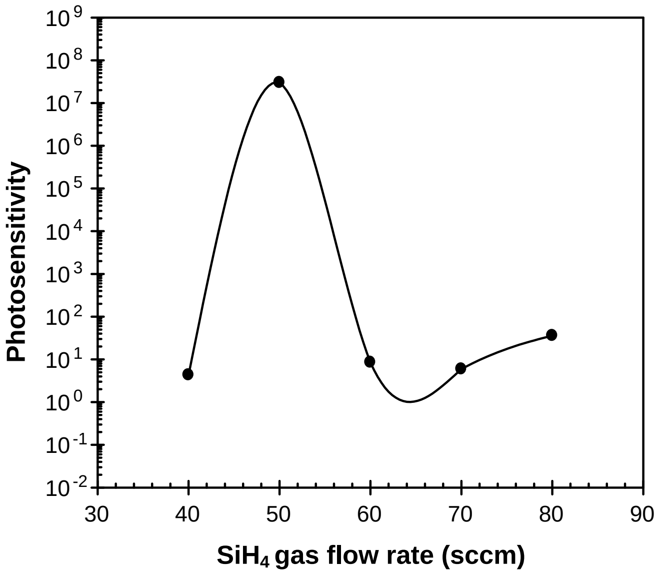

Figure 6 Photosensitivity of the silicon thin films as a function of the SiH_4 gas flow rate.

For future work, the photosensitivity of the resulted silicon thin films was then analyzed for solar cell application, as shown by Figure 6. The highest sensitivity was obtained from the film using the SiH_4 gas flow rate of 50 sccm. The highest photosensitivity of 3×10^7 achieved is higher than the minimal value of 10^3 for solar cell application.

4 Conclusions

In this research, the new alternatif technique, namely HWC-VHF-PECVD technique for growth of μc-Si:H has been developed. In general, the resulted thin films using this technique showed higher deposition rate than the conventional PECVD technique or conventional VHF-PECVD technique at the same deposition condition. The deposition rate up to 3.6 Å/s was obtained using the technique, while the deposition rate of the conventional PECVD still below of 1.0 Å/s [13] and the higher deposition rate of the conventional VHF-PECVD technique only reached of 2.2 Å/s [8].

The best microstructure of the resulted μc-Si:H thin film was obtained using the SiH_4 gas flow rate of 70 sccm. The lowest optical bandgap of 1.4 eV and high enough dark conductivity of 2.29 x 10^{-5} S/cm were obtained at 60 sccm. The optimum characteristic of resulted silicon thin film for solar cell application was obtained using the SiH_4 gas flow rate of 50 sccm, where its photosensitivity in the order of 10^7. The results show that the HWC-VHF-PECVD is potentially promising technique for fabrication of the stacked solar cell application.

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