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Deposition of Hydrogenated Microcrystalline Silicon Germanium using HWC-VHF-PECVD Method

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Abstract

The hydrogenated amorphous silicon germanium (a-SiGe:H) has commonly deposited using Hot Wire Cell Plasma Enhanced Chemical Deposition (HWC-PECVD). However, low photoconductivity of the resulted a-SiGe:H leads to the effort for further improvement. Therefore, to increase the material quality, the hydrogenated microcrystalline silicon germanium (μc-SiGe:H) has been deposited using another method namely Hot Wire Cell Very High Frequency Plasma Enhanced Chemical Deposition (HWC-VHF-PECVD). By using low deposition temperature of 275 ^{o}C and low filament temperature of 200 ^{o}C, the grain sizes of the SiGe alloy microcrystalline structure were clearly shown by the surface profile of Scanning Electron Microscope (SEM) measurement. As the power discharge varied from 10 watt to 30 watt, the high photoconductivity of 3.03×10^{-4} S/cm and the low optical band gap of 1.58 eV were obtained.

1. Introduction

The hydrogenated amorphous silicon (a-Si:H) solar cells have attracted much attention due to the low cost and large area producibility. However, the conversion efficiency of such cell is limited by the low absorption of a-Si:H in the long wavelength region and the degradation of a-Si:H material due to the Staebler–Wronski effect. To overcome these problems, many investigations have been made, and the most meaningful is the use of tandem solar cell. In a tandem solar cell, long wavelength region of solar spectrum can be utilized by using a narrow band gap material.

Narrow band gap silicon (Si) and Germanium (Ge) alloys have attracted a great deal of attention for application in the tandem solar cells, because its optical band gap can be tailored by changing the Ge content to match longer wavelengths of the solar spectrum. However, as the Ge content increases and the band gap decreases, the electronic and structural properties of the films tend to be inferior [1]. Various methods have been applied for SiGe alloy deposition, such as Hot-wire Chemical Vapor Deposition (HWCVD) [1-3], Plasma Enhanced Chemical Vapor Deposition (PECVD) [4-6], Sputtering [7-8], and Electron Cyclotron Resonance (ECR) [9]. However, for the SiGe alloy utilization in tandem solar cells, the low defect density should be achieved for amorphous semiconductor and the deposition of this material must be carried out at low substrate temperatures in order to protect the previously fabricated layers from degradation. On the other hand, the decrease of the substrate temperature leads to deterioration of electronic properties due to the increase of SiH_2 bonds related microstructure [6].

We have developed a new method, named as the Hot Wire Cell Very High Frequency Plasma Enhanced Chemical Vapor Deposition (HWC-VHF-PECVD), that commonly be used for the deposition of a-Si:H and μc-Si:H thin films with high enough quality [10]. An electrode system with capacitive coupling was used inside the chamber. While, a heated spiral tungsten filament was integratedly placed with the system of gas source inlet. The plasma gas was generated using the 70 MHz rf power. In this study, we investigated the possibility of optimizing the properties of SiGe alloy using the HWC-VHF-PECVD method in order to obtain the μc-SiGe:H thin film with high quality for tandem solar cell application.

2. Experiments

The SiGe alloy thin films were prepared onto the 15 mm x 20 mm of Corning 7059 glass substrates by alternating deposition from the plasma of 10% SiH_4 gas diluted in H_2 and 10% GeH_4 gas diluted in H_2 in the HWC-VHF-PECVD chamber system. The schematic diagram of HWC-VHF-PECVD chamber system was shown in Fig.1. In this preliminary study, we only investigated the influence of rf power discharge to the quality of resulted thin films. The rf power discharge was varied from 10 watt to 30 watt, while the other parameters were kept constant such as substrate temperature of 275 ^{o}C, filament temperature of 200 ^{o}C, chamber pressure of 300 mTorr, SiH_4 gas flow rate of 70 sccm, and GeH_4 gas flow rate of 0.1 sccm.

The properties of resulted μc-Si:H thin films which are the optical band-gap and the thickness were analyzed using the Ultra-Violet Visible (UV-Vis) spectroscopy, the structural analysis was conducted using the X-ray Diffraction (XRD) and the Scanning Electron Microscope Energy Dispersive X-ray (SEM-EDX), and the conductivity measurement using Keithley 617 two-probe method. The conductivity was measured in two different conditions i.e. in the dark condition for dark conductivity measurement and under 34 mW/cm^2 of intensity illumination for photoconductivity measurement. The data ratio of photoconductivity to dark conductivity is then defined as photosensitivity data.

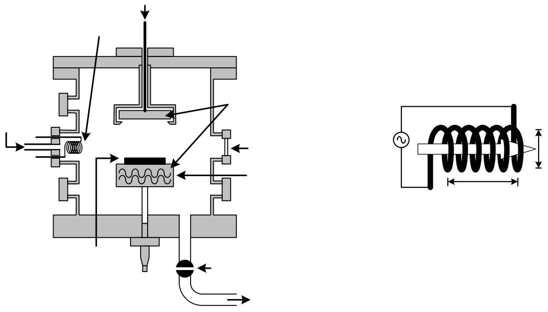


Figure 1: (a) Schematic diagram of the HWC-VHF-PECVD chamber system, (b) The dimension of the tungsten filament induction.

3. Results and Discussion

As known that the presence of the heated filament in the 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 [11]. The effectiveness of gas molecules decomposition in the inter-electrode electrical field is influenced by the applied rf power discharge, which was as main investigated parameter in this study. In general, the formation of simple radical was more effective in the high power discharge condition. However, ionic radical bombardment on the deposited film surface must be considered during experiment.

Figure 2 shows the deposition rate and the optical band gap of resulted SiGe alloy. As seen that the deposition rate generally increase as the rf power discharge increase, which were in line with the generally degradation of their optical band gap. The highest deposition rate of 8.04 Å/s was obtained from 30 watt of rf power, while the lower optical band gap of 1.58 eV was obtained from 15 watt of rf power.

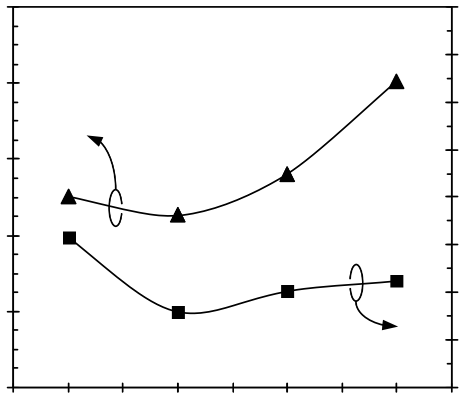


Figure 2: Deposition rate and optical band gap characteristic of resulted SiGe alloy thin films as a function of rf power discharge.

The above showed such properties were commonly assumed as the improvement of material structure in one side or the increasing of germanium content in another side. The increasing of deposition rate indicates that the amount of simple radicals in plasma is increase, due to the application of higher rf power discharge. Furthermore, the increasing of Ge content in the deposited thin film degrades their optical band gap. However, in order to get the complete analysis, the above results must be cross-checked with the result of their electrical properties and their structural measurements. Figure 3 shows the electrical properties of resulted SiGe alloy. The highest dark conductivity of 2.02 x 10^{-10} S/cm was obtained from 15 watt of rf power, while The highest dark conductivity of 3.03 x 10^{-4} S/cm was obtained from 20 watt of rf power.

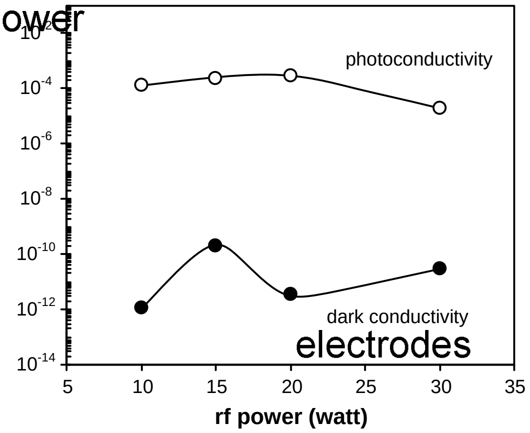
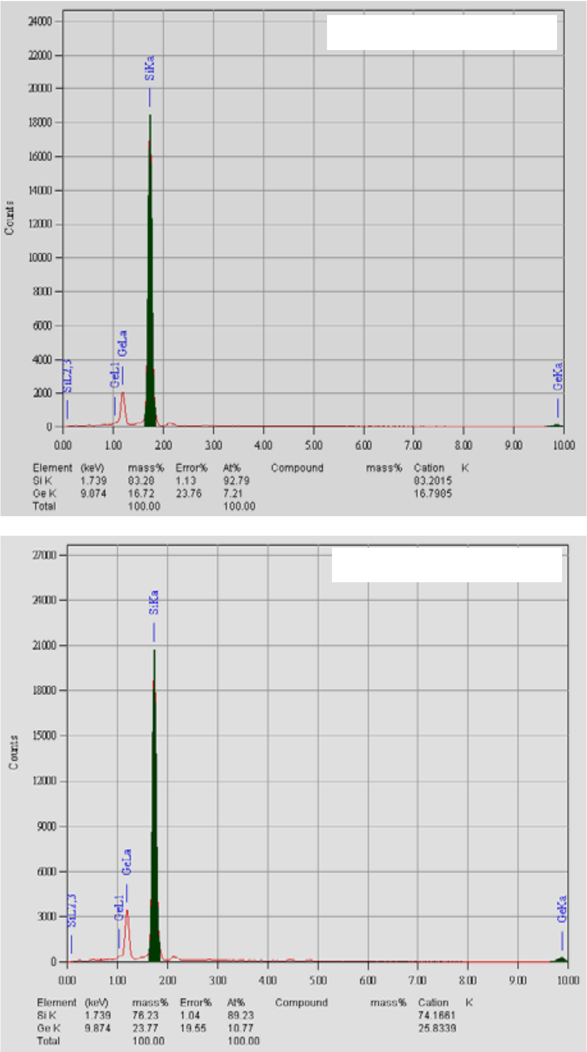


Figure 3: Conductivity of resulted SiGe alloy thin films as a function of rf power discharge.

As seen that the highest dark conductivity was parallel to the lower optical band gap, which were obtained from 15 watt of rf power. This indicates the improvement of material structure, in contrast with the material quality that obtained from 10 watt of rf power. The dark conductivity then decreases as the rf power increases from 15 watt to 20 watt. Compared to the deposition rate and the optical band gap, the decreasing of dark conductivity was probably affected by the increasing of Si content in resulted material due to the rf power increase from 15 watt to 20 watt, that supported by the increasing of its photoconductivity. The estimation that the high Ge content would has low photoconductivity can be explained using EDX measurement. Figure 4 shows the result of EDX analysis of obtained SiGe alloys. As seen that the Ge content increase from 16.72% to 23.77% as the rf power increase from 20 watt to 30 watt, which parallel to the decrease of its photoconductivity.

In this study, we also analyzed the structural properties of resulted SiGe alloy by SEM measurement as shown by surface profile in Figure 5. The grains that indicate the formation of microcrystalline structure were clearly seen. However, another measurement method such as X-ray Diffraction (XRD) analysis is expected in order to identify its microcrystalline grain size and orientation.



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Element  (keV)   mass%   Error%  At%     Compound        mass%   Cation   K
Si K     1.739   83.28   1.13    92.79                           83.2015
Ge K     9.074   16.72   23.76   7.21                            16.7985
Total            100.00          100.00
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Element  (keV)   mass%   Error%  At%     Compound        mass%   Cation   K
Si K     1.739   76.23   1.04    89.23                           74.1661
Ge K     9.874   23.77   19.55   10.77                           25.8339
Total            100.00          100.00
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Figure 4: EDX analysis of SiGe alloy that obtained from 20 watt rf power (a) and 30 watt rf power (b).

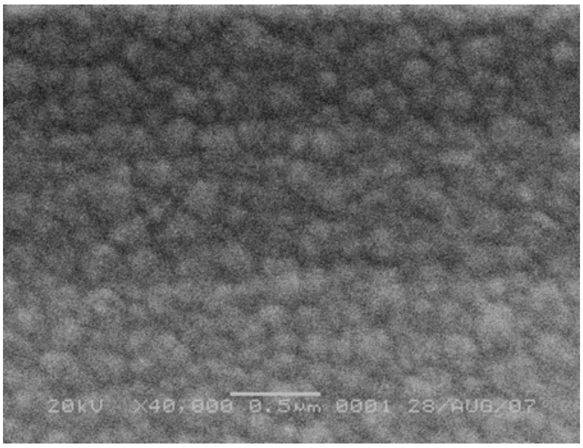

Figure 5: Surface profile by SEM analysis of SiGe alloy that obtained from 20 watt rf power.

4. Conclusion

In this study, the μc-SiGe:H with good enough quality can be deposited using HWC-VHF-PECVD. The optoelectronic properties of resulted SiGe alloy were strong influenced by the ratio of Si and Ge content in the film. The highest optical band gap of 1.58 eV was obtained from 15 watt rf power and then increase as the rf power increase, while the highest deposition rate of 8.04 Å/s was obtained from 30 watt of rf power that generally increase as the rf power increase.

By the EDX analysis that compared to the electrical properties, the increasing of Ge content in the film degraded its photoconductivity, in contrary to the increasing of Si content of film. Finally, the formation of microcrystalline structure of resulted SiGe alloys was clearly seen from its surface profile of SEM measurement.

5. Acknowledgements

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