

Characterization of $\mu\text{-Si:H}$ Thin-film Solar Cells by Hot-wire CVD

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Abstract - Microcrystalline silicon(c-Si:H) thin-film solar cells are prepared with intrinsic Si-layer by hot wire CVD. The operating parameters of solar cells are strongly affected by the filament temperature (T_f) during intrinsic layer. J_{sc} and efficiency abruptly decreases with elevated T_f to 1400°C. This deterioration of solar cell parameters are resulted from increase of crystalline volume fraction and corresponding defect density at high T_f . The heater temperature (T_h) are also critical parameter that controls device operations. Solar cells prepared at low T_h (<200°C) shows a similar operating properties with devices prepared at high T_f , i.e. low J_{sc} , Voc and efficiency. The origins for this result, however, are different with that of inferior device performances at high T_f . In addition the phase transition of the silicon films occurs at different silane concentration (SC) by varying filament temperature, by which highest efficiency with SC varies with T_f .

1. INTRODUCTION

Microcrystalline silicon (c-Si:H) thin films have been considered to be one of the promising materials for low cost and highly efficient solar cells. Through out the intensive studies from many research groups[1-3], considerable results have recently achieved for c-Si:H thin film solar cells. Kaneka corp. has successfully fabricated c-Si:H thin film solar cells with about 10% efficiency in pin single junction and 14% by tandem with a-Si:H cell[4]. It must be interesting facts that solar cells with high conversion efficiency have been made by only one deposition method, i.e. PECVD. However, PECVD method has drawbacks in view of mass production since deposition rate of c-Si:H thin films are very low for high H dilution. Although VHF CVD method are advantageous in deposition rate and device performances, system scale-up for large area deposition has been main obstacle. Therefore, further progresses in deposition techniques are required in view of mass production as well as device performances.

Hot wire (HW) chemical vapor deposition method has attracted much attention due to its feasibility both for fast deposition of c-Si:H thin films and for mass production by up-scaling. However, the quality of the c-Si:H thin films prepared hot wire method has been considered inferior to material quality by conventional PECVD. The c-Si:H films prepared by HW-CVD are defect rich, porous and subject to in-diffusion of atmospheric gases although crystalline properties, e.g. large grain size and high crystalline volume fraction, are superior to the materials by glow discharge methods. By these reasons, solar cell efficiencies incorporating HW intrinsic c-Si:H films are low compared to that of PECVD cells. However, Julich group has identified that the substrate temperature is key parameter for controlling both the c-Si:H film quality and corresponding

solar cell performances[5]. This group recently developed c-Si:H thin-film solar cells with conversion efficiency of 9.4% at low substrate temperature by hot wire method[6]. However, the effects of filament temperature (T_f) on solar cell performances have not been mentioned. A T_{in} HW-CVD method should be most critical parameter since gas decomposition occurs at filament surface. The effects of T_f on structural properties of c-Si:H and poly-Si films have been studied in our previous study[7].

In the present paper, we prepared c-Si:H thin-film solar cells by hot wire CVD and investigated the effect of deposition parameters, especially filament temperature, on the film properties and solar cell performances.

2. EXPERIMENTAL

The c-Si:H thin-film solar cells are prepared on glass (Corning 1737) substrate. The ZnO:Al front transparent TCO are deposited by rf magnetron sputtering method and surface are wet etched in 0.5% HCL solution. The B-doped p c-Si:H and P-doped n a-Si:H films are deposited by 13.56MHz PECVD separately in multi-chamber deposition system. Intrinsic c-Si:H thin-films are prepared by hot wire CVD that is also *in-line* connected with the system. Fig. 1 shows photograph of HWCVD chamber inside. Two straight Ta-filaments with 0.5mm diameter and 17cm long are mounted with gas distributor (GD). The distance between filament and GD surface was fixed to 2.5cm, and filament to glass distance (dfg) varied from 1 to 8cm by vertically moving the substrate.

The solar cells are characterized by I-V measurement at AM 1.5 solar simulator and external quantum efficiency. For crystalline properties analysis Raman spectroscopy are carried out both on the c-Si:H thin-films and on the solar cells. Dark and photo conductivity are measured with co-planar structure.

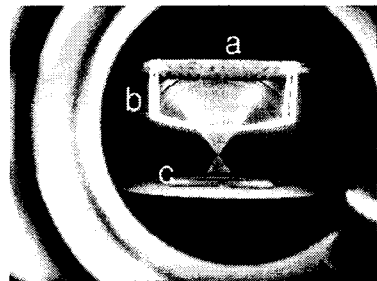


Fig. 1. Photograph of HWCVD chamber inside : (a) gas distributor, (b) Ta filament and (c) glass substrate on graphite plate mounted over heating block.

3. RESULTS AND DISCUSSION

3.1 Effect of Filament and Heater Temperature

This section describes the effect of filament and heater temperature (T_f & T_h) on the operating properties of solar cells incorporating HW intrinsic c-Si:H thin films. The solar cells are fabricated at the same conditions for front TCO, p & n layer and back reflector, while intrinsic c-Si:H thin films are prepared under the different T_f and T_h by hot wire CVD. The intrinsic layers are deposited at 7% of silane concentration (SC: percentile amount of SiH₄ gas among total gases), 30mTorr of gas pressure and 6.7cm of filament to glass distance. The thickness of each layer is fixed to about 0.5μm for textured ZnO:Al front TCO, 20nm for p c-Si:H, 2μm for intrinsic layer and 30nm for n a-Si:H. The areas of solar cells are defined to 0.25cm² by Ag/Al back electrode. Fig. 2 shows the variation of solar cell performances with the variation of T_f and T_h . When T_f increases from 1300 to 1350 °C, the small decrease of open circuit voltage(Voc) and fill factor(FF) observed, and short circuit current density(Jsc) and efficiency(η) contrarily increase. On the contrary, 50 °C increase of T_f from 1350 to 1400 °C gives a severe deterioration of solar cell operation.

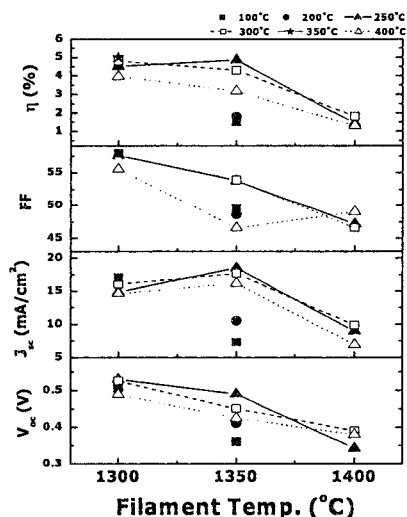


Fig. 2. Operating properties of c-Si:H thin film solar cells vs filament temperature during the deposition of HW intrinsic layer.

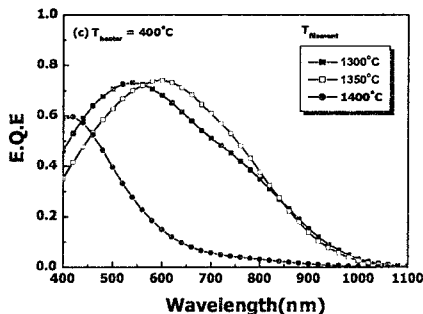


Fig. 3. Variation of external quantum efficiency of solar cells with different filament temperature.

Fig. 3 shows external quantum efficiency(EQE) of solar cells that have intrinsic c-Si:H thin film deposited at different T_f . It should be noted that the collection efficiency of solar cells prepared at T_f 1400 °C is very low at whole wavelength range. This limited collection efficiency well matches with the low Jsc(less than 10mA/cm²) of solar cells prepared at highest filament temperature(1400°C).

Fig. 4 shows the co-relation of conduction properties and crystalline volume fraction (V_f) of the HW c-Si:H films deposited at different T_f . The dark conductivity (d) linearly increases from 10⁻⁸ to 10⁻⁷S/cm with increasing T_f . It is speculated that the increase of d with T_f should be caused by increased volume fraction of the Si-films as captioned inside the figure, i.e. V_f increases from 53% to 75%. The photo conductivity (p), however, are almost same regardless of the T_f , by which photo sensitivity (S) is inverse proportion to filament temperature.

Fig. 5 shows the FTIR spectra of HW c-Si:H thin films as function of T_f . While Si-Hx stretching mode near 2090cm⁻¹ dominantly occurs in the Si films deposited at T_f 1400°C, the absorption peak moves to lower wavenumber as T_f decreases to 1290°C. It should be noted that the films deposited at T_f 1360°C have Si-H bonding structure dominantly. This means that the quality of c-Si:H films prepared at lower T_f are better than that of high T_f samples since the absorption peak at 2090cm⁻¹ is attributed to the bonded hydrogen on crystalline surface and act as defects[8].

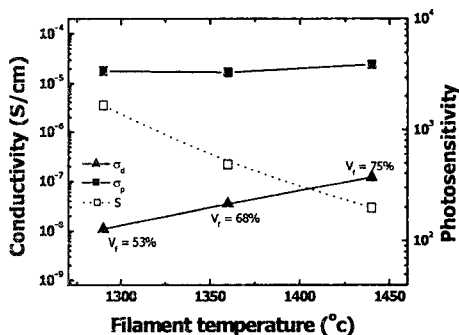


Fig. 4. Variation of conduction properties of the HW c-Si:H thin film vs filament temperature.

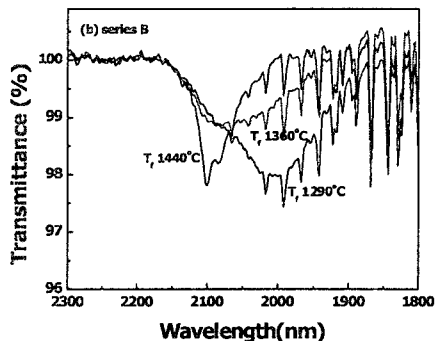


Fig. 5. FTIR spectra of the HW c-Si:H thin film vs filament temperature.

Fig. 6 shows the effect of heater temperature (T_h) during the deposition of HW intrinsic layer on solar cell operation. As described above the graph, the deposition conditions of i c-Si:H are SC 7%, T_f 1340-1360°C and pressure 30mTorr. The open circuit voltage V_{oc} has very low value at heater temperature less than 200°C and has maximum value of about 500mV at T_f 250°C. The j_{sc} has almost same tendency with V_{oc} , i.e. it increases from 10mA/cm² to 19mA/cm² with 50°C increase of T_h from 250°C. On the other hand, fill factor shows maximum at T_f 250 °C and decreases markedly at both lower and higher T_f than 250°C. By these parameters, the efficiency of solar cells have similar trend with V_{oc} and j_{sc} curves. About 5% efficiency was achieved at T_h 250 °C. The results of spectral response are also shown in Fig. 7. While the similar collection efficiencies are obtained at T_f more than 250°C, it considerably decreases at lower temperature than 250°C.

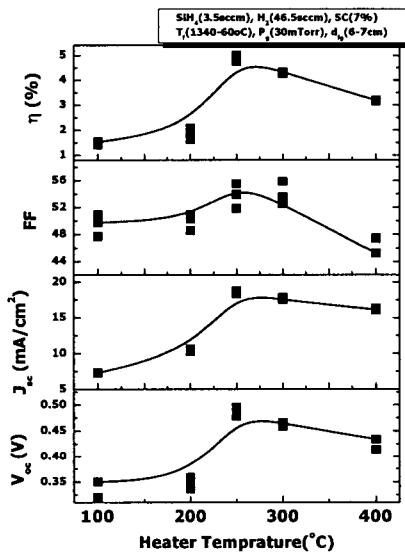


Fig. 6 Operating properties of c-Si:H thin film solar cells vs heater temperature during the deposition of HW intrinsic layer

From the above results, we can draw the following conclusions;

The filament temperature should be critical parameter to determine the quality both of intrinsic Si-films and of solar cells. The T_f higher than 1400°C gives a considerable decrease of solar cell parameters, especially of j_{sc} less than 10mA/cm².

These low j_{sc} resulted from low collection efficiency at 450-1100 wavelength. The reduced spectral response may be due to the increased defect density within the c-Si:H films by enhanced crystalline properties and corresponding increase of defect densities with T_f . This is partly clarified Si-H bonding structure as shown in Fig. 5.

The similar tendency of j_{sc} variation was observed when heater temperature decreased less than 200°C, i.e. the spectral response curves of the solar cells prepared at low heater temperature are almost same with that of T_f 1400°C.

The origin of low j_{sc} and spectral response of these low T_h cells, however, are entirely different with that of high T_f

(1400°C) cells. While the low j_{sc} and collection efficiency of high T_f cells are caused by high crystallinity and defect density with elevated T_f , the low T_h cells have inferior properties resulted from low crystallinity. The intrinsic Si-films deposited at T_h lower than 200°C are carefully supposed to be amorphous phase.

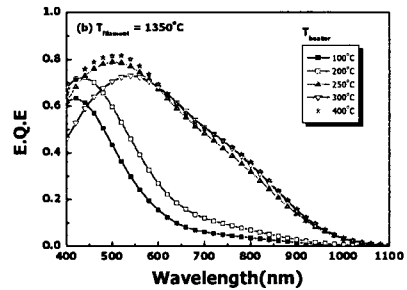


Fig. 7. Variation of external quantum efficiency of solar cells with different heater temperature.

4. CONCLUSION

In this paper, c-Si:H thin-film solar cells are prepared by HW-CVD. The filament temperature plays a critical role both to material quality of Si-films and operating properties of solar cells. The solar cells that have c-Si:H absorber prepared at T_f 1400°C have very low short circuit current density and collection efficiency. Optimum silane concentration that gives maximum solar cell efficiency was also affected on the filament temperature. While optimum SC locates at 8% in case of T_f 1300°C, it moves to 5% when T_f increases to 1350°C. Raman analysis of these solar cells shows that the phase transition region from c-Si:H to a-Si:H occurs at different silane concentration, by which solar cell parameters are affected since c-Si:H solar cells reportedly have maximum efficiency at phase transition point. The partially optimized solar cells showed a conversion efficiency of 6.3%.

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