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EFFECT OF NUMBER OF FILAMENTS ON THE STRUCTURE, COMPOSITION AND ELECTRICAL PROPERTIES OF μC-SI:H LAYERS DEPOSITED USING HWCVD TECHNIQUE

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Influence of the number of filaments on the deposition rate, structural, compositional and electrical properties of hydrogenated microcrystalline silicon (μc-Si:H) deposited by hot wire chemical vapor deposition (HWCVD) has been studied. Also a systematic study of the variation of silane concentration in the silane + hydrogen gas mixture has been done for different number of filaments. The films are characterized by Raman and FTIR spectra to see the crystalline volume fraction and composition respectively. Dark and photoconductivity measurement have been done to see the electrical properties of the material. Cross section SEM and AFM studies also have been done to see their structure and surface morphology.

The advantage of using 8 filaments is that the deposition rate of the μc-Si:H films is higher as compared to films deposited with 4 filaments without deteriorating the quality of μc-Si:H films. Some more interesting results are observed here. The post deposition oxygen uptake is lower for films deposited with 6 sccm and beyond silane flow for the 8 filaments case, while in case of 4 filaments the oxygen uptake is lower beyond 3 sccm silane flow. Another difference is that these films become totally amorphous for 8 sccm silane flow with 8 filaments while in case of 4 filaments the film becomes amorphous when 7 sccm silane flow is maintained. Thus it is confirmed that a higher number of filaments aid in the formation of crystalline film. Moreover the hydrogen content in films is also low with higher number of filaments.

Keywords: *HYDROGENATED MICROCRYSTALLINE SILICON, HWCVD, FTIR, RAMAN, CROSS SECTIONAL SEM, AFM.*

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1. INTRODUCTION

μc-Si:H is an interesting semiconductor material which has the required properties for large area thin film photovoltaics [1-3]. μc-Si:H is a promising material for low energy photon (near IR) absorption in thin film solar cell and bottom cell in Micromorph tandem solar cell. When, silane is diluted with hydrogen during deposition, a mixed phase of small crystals and amorphous silicon get deposited. Hydrogen dilution is the key factor of preparing μc-Si:H material [4, 5]. Different deposition techniques yield different quality films. HWCVD is a fairly developed technique for a-Si:H and μc-Si:H thin films material [6-9]. Generally high hydrogen dilution, low pressure, low silane flow, high substrate and filament temperature are required for formation of microcrystalline silicon material [10, 11]. The microstructure and electronic properties of this material can be controlled by varying the deposition

parameters. There are still a lot of challenges in field of microcrystalline silicon such as oxidation during and post deposition, microstructure, crystalline volume fraction, hydrogen content and electronic transport. The main drawback of this material is the low absorption coefficient for light (10^2-10^3 cm^{-1} for $\lambda > 700$ nm), so ~ 2 μm thick layer is required for efficient absorption of radiation. Thus high deposition rate device quality μc-Si:H material is necessary for industrial manufacturing.

By HWCVD technique, the desired quality microcrystalline silicon can be achieved by varying the different deposition parameters. Hydrogen content, crystalline volume fraction, grain size, crystal orientation and electrical property of the deposited material can be controlled. Number of filaments is an important factor. Deposition rate of μc-Si:H films can be increased by increasing the number of filaments which is the basic requirement for μc-Si:H based solar cells. But with increasing number of filaments other properties of the material also change effectively. A systematic study of silane flow variation has been done here with four and eight filaments at substrate temperature of 210 °C. Thus the main goal of this work is to see the effect of number of filaments on the deposition rate, structural, compositional and electrical property of μc-Si:H deposited by HWCVD technique.

2. EXPERIMENTAL DETAILS

μc -Si:H films are deposited using HWCVD at substrate temperatures (T_s) of 210 °C in base pressure of 10^{-6} to 10^{-7} Torr with four and eight number of tantalum filaments.

Set I: SiH_4 is varied from 2-8 sccm with 50 sccm H_2, Filament temperature (T_{Fil}) and deposition pressure (p) maintained at 1650 °C and 50 mTorr respectively with four filaments.

Set II: SiH_4 is varied from 2-8 sccm with H_2, Filament temperature (T_{Fil}) and deposition pressure (p) maintained at 1650 °C and 50 mTorr respectively with eight filaments.

Tantalum filament of 0.5 mm diameter is used as a HWCVD catalyst. Four and eight filaments of 10 cm length are used for dissociation of process gases and distance between two filaments is around 2 cm and 1cm respectively as shown in Figure 1. Corning 1737 glass substrates are cleaned sequentially in a bath containing de-ionized water and methanol with ultrasonic agitation for 10 minutes. μc -Si:H films were also deposited on n-type ⟨100⟩ Silicon wafers for FTIR analysis. These *n*-type ⟨100⟩ Silicon wafers are cleaned in the same manner as that for corning glass after hydrofluoric (HF) acid dip. The samples are characterized for hydrogen content [12] by Fourier transform infrared (FTIR spectrometer – JASCO), thickness (Dektak 150 surface profilometer), microstructure by Raman spectroscopy [13] (Raman spectrometer – Jobin-Y von RAMNOR HC-2S spectrometer) and dark and photo conductivity (Keithley-2400 source meter). Further characterization of the structure was done by scanning electron microscopy and Atomic force microscopy (SEM – Hitachi-S3400 and AFM – Nanoscope IV).

3. RESULTS AND DISCUSSION

Silane concentration has been varied with four and eight filament geometry (Fig. 1) to study the effect of number of filaments on deposition rate and other properties of μc-Si:H films. From Figure 2, it is clear that the

deposition rate of μc-Si:H films increases up to 7 Å/s with increasing SiH_4 concentration. The comparison of deposition rate of μc-Si:H films with 4 and 8 number of filaments is shown in Figure 2. The deposition rate is higher in case of eight filaments. Higher dissociation of silane takes place with higher number of filaments. Higher dissociation of silane gas will create more film producing species thus increasing the deposition rate of μc-Si:H films.

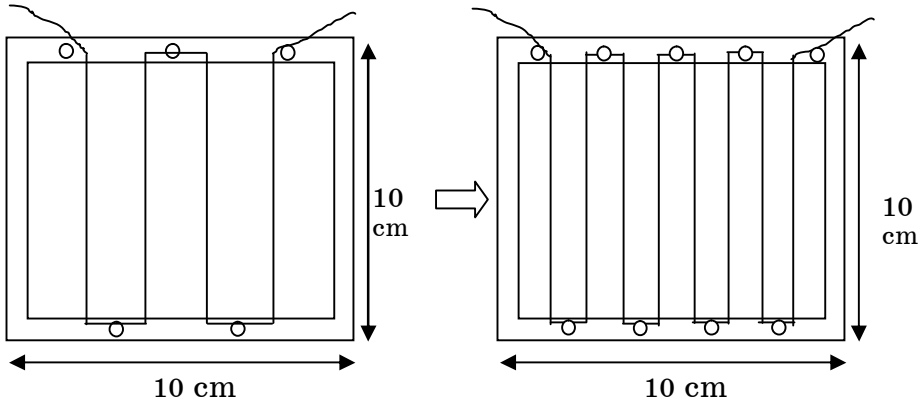

Fig. 1 – *Schematic of filament holder with different number of filaments*

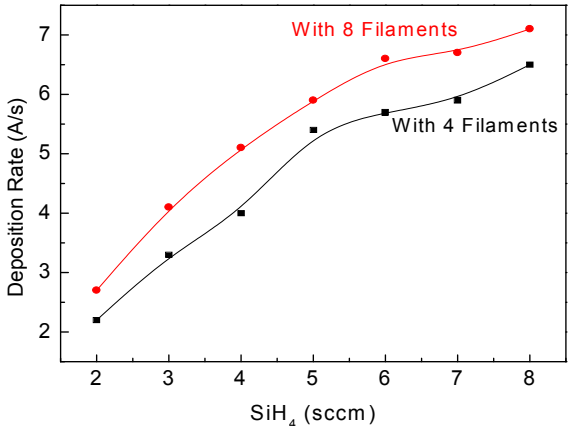

Fig. 2 – *Deposition rate of the μc-Si:H films as a function of silane with* 50 *sccm* H_2 *flow and deposited with* 4 *and* 8 *filaments*

Hydrogen content in the material is calculated from the FTIR spectra [12]. Hydrogen content is lower in case of higher number of filaments as shown in Figure 3. This is because at higher number of filaments more hydrogen atoms get generated due to higher dissociation of process gases (SiH_4 and H_2) leading to effective abstraction of the bonded hydrogen from the film.

From the FTIR spectra of μc-Si:H films (Figure 4) deposited with eight filaments it is observed that below 6 sccm silane concentration the films contain a large amount of oxygen which is confirmed by the intense Si-O peak at around at 1050 cm^{-1}. The oxidation of the film occurs after deposition because of the porous material. This is confirmed by the presence of the Si-H_2

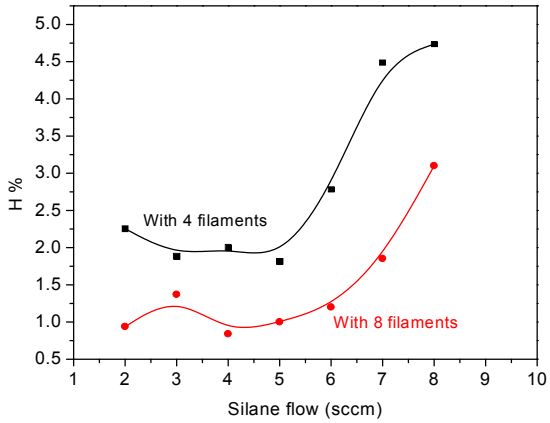

Fig. 3 – *Hydrogen content of the μc-Si:H films deposited at different silane with* 50 *sccm* H_2 *concentrations with* 4 *and* 8 *filaments*

peak at around 2100 cm^{-1} in the FTIR spectra which is indicative of a high microvoid density in the film. But after 6 sccm silane concentration, there is no significant amount of oxygen and the film is still microcrystalline in nature. The film becomes totally amorphous after 8 sccm silane flow (as confirmed by Raman data).

An interesting observation here is that oxygen uptake is lower for 6 sccm silane flow and beyond while in case of 4 filaments films oxygen uptake is lower after 3 sccm silane flows. The reason is that at higher number of filaments, film may become structurally poor and are prone to oxidation.

From Raman spectra analysis of μc-Si:H films deposited with eight filaments it is observed that films are crystalline in nature till 8 sccm SiH_4 concentration and after that there is a phase transition from microcrystalline silicon to amorphous silicon (Si-Si TO peak shifts from 518 cm^{-1} towards 480 cm^{-1}). The crystalline volume fraction (shown in Fig. 5) deduced from the Raman data reveals that the silane concentration affects the micro-structure of the films and crystalline volume fraction decreases with increasing SiH_4 concentration.

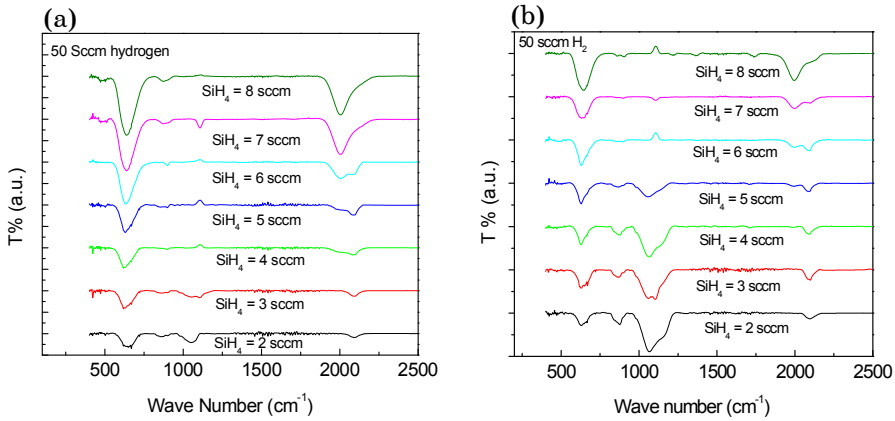

Fig. 4 – *FTIR spectra of the μc-Si: H films deposited at different silane with* 50 *sccm* H_2 *flow with* 4 *(a) and* 8 *(b) filaments*

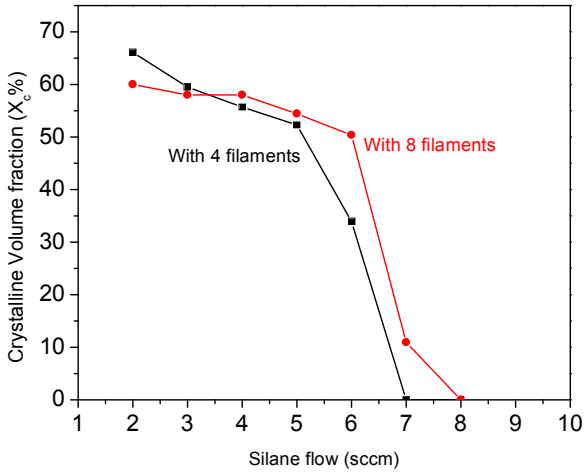

Fig. 5 *– Crystalline volume fraction of the μc-Si: H films deposited at different silane with* 50 *sccm* H_2 *concentrations with 4 and 8 filaments*

One another interesting difference is that the crystalline volume fraction is higher in case higher number of filament and these films became amorphous after 8 sccm silane flow with eight filaments while in case of 4 filaments, the films become amorphous after 7 sccm silane flow. Thus it is confirmed that crystalline nature of films increases with increasing number of filaments. The reason behind it is that higher number of filaments dissociates more amount of atomic hydrogen which helps to make the films more crystalline in nature.

The dark and photoconductivity of μc-Si:H films deposited with four and eight filaments were measured. Dark conductivity decreases while photoconductivity increases with increasing silane concentration in both cases with 4 and 8 filaments. There is no significant photoconductivity gain in films which have oxidized. It is also observed that the μc-Si:H films which have no oxygen content have photoconductivity gain of more than one order of magnitude which increases with increasing silane concentration.

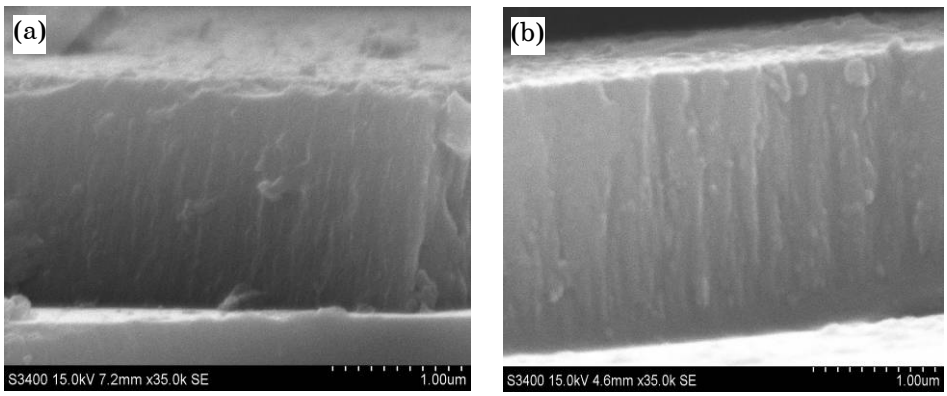

Fig. 6 *– Cross sectional SEM images of the μc-Si:H films deposited with a)* 4 *and b)* 8 *number of filaments*

Cross sectional SEM images (Figure 6) were taken to see the structure of material. A vertical columnar structure is clearly seen in both cases with 4 and 8 filaments which is a characteristic of device quality μc-Si:H films. AFM (Figure 7) images were taken to see the surface morphology of these films. The average roughness of the μc-Si:H films is between 5 to 7 nm, which decreases with increasing silane concentration.

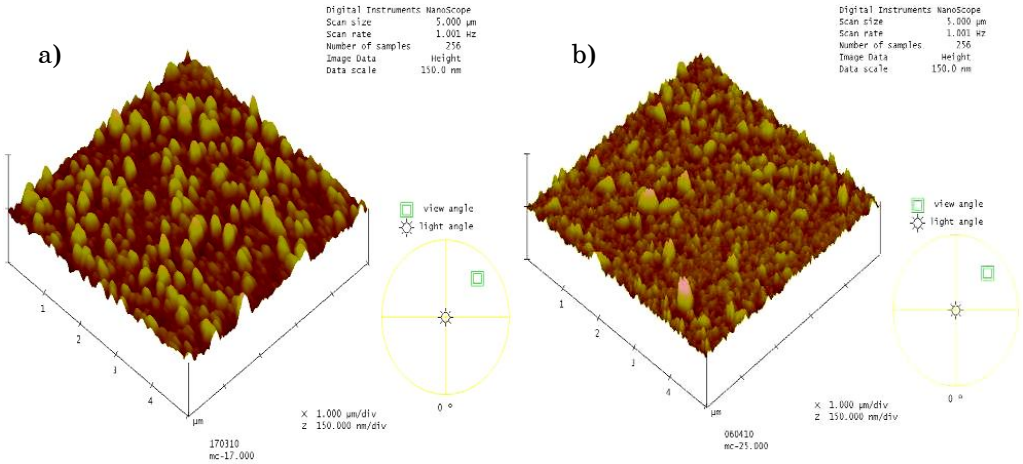

***Fig. 7** – AFM image of the μc-Si:H films deposited at 5 sccm silane concentration with 50 sccm H_2 dilution with 4 (a) and 8 (b) filaments*

4. CONCLUSION

Influence of number of filaments on the deposition rate, structural, compositional and electrical property of μc-Si:H deposited by HWCVD has been studied. The deposition rate of μc-Si:H films deposited with 8 filaments is higher as compared to films deposited with 4 filaments. The oxygen uptake is lower in the films after 6 sccm silane concentrations with 8 number of filaments while in case of 4 number of filaments oxygen uptake is lower after 3 sccm silane concentrations. Another interesting result is that these films become totally amorphous after 8 sccm silane concentrations while in case of 4 filaments, films become amorphous after 7 sccm silane concentration. Thus the crystalline nature of μc-Si:H film increases with increasing number of filaments. Hydrogen content is also observed to be lower for higher number of filaments.

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