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DESIGNING SINGLE CHAMBER HWCVD SYSTEM FOR HIGH DEPOSITION RATE DEVICE QUALITY A-Si:H THIN FILMS AND SOLAR CELLS

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A new single chamber HWCVD with vertically mounted substrates and filaments has been designed for depositing device quality a-Si:H *films with high deposition rate. Optimization studies on films deposited in this chamber under a variety of deposition conditions yielded uniform films at more than 7Å/sec deposition rate and with very low oxygen content. These films show a photoconductivity gain of more than* 10^5. *The working pressure has been kept quite low at* 15 *mtorr compared to earlier studies. i-layers of a p-i-n single junction solar cells were deposited on the TCO (Asahi-U type) glass in this reactor. The initial p-layer and the final n-layer were deposited in another system with separate chambers for these doped layers thus exposing the p-layer as well as the i-layer to the atmosphere during the transfer. Using this optimized intrinsic layer,* a-Si:H *based p-i-n solar cell showed a conversion efficiency of* 4.7 %.

Keywords: *HYDROGENATED AMORPHOUS SILICON, HWCVD, FTIR, RAMAN SPECTROSCOPY, DARK AND PHOTOCONDUCTIVITY.*

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1. INTRODUCTION

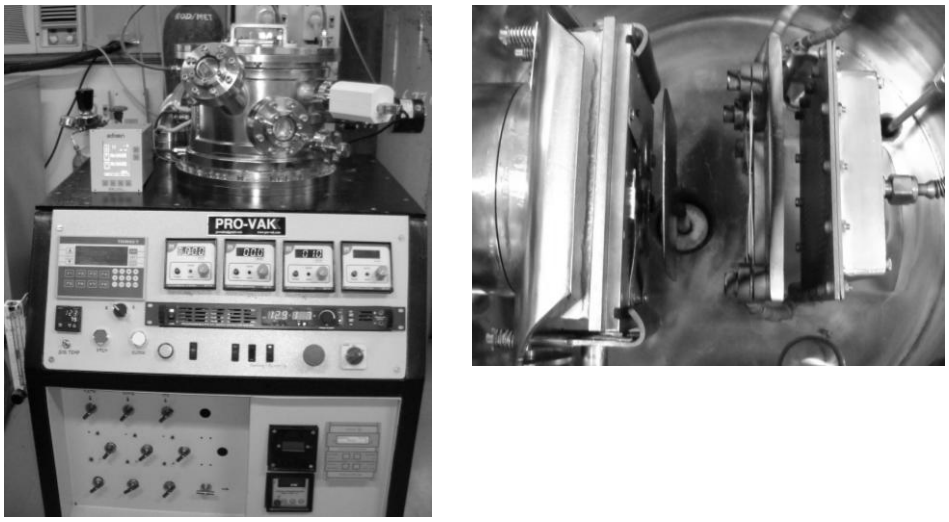
Hydrogenated amorphous silicon (a - Si:H) is found to have important electronic properties due to its short range ordered structure and hence it is being extensively used in optoelectronic and photovoltaic applications. The performance of the device depends on the quality of the a - Si:H intrinsic film having minimum bulk defect states. a - Si:H based thin films can be deposited by various methods. We have been involved in the Hot Wire Chemical Vapor Deposition (HWCVD) of a - Si:H and its various alloys for a long time. In order to increase the deposition rate for device quality a - Si:H films we have made several attempts till now. It is seen that this method has some advantages over conventional PECVD in terms of high deposition rate, ion free deposition atmosphere and possibility of large area up-scaling [1, 2]. Recently we have designed a single chamber HWCVD system with vertical filament-substrate geometry for the deposition of high growth rate device quality a - Si:H intrinsic thin films. These films were optimized at different deposition pressures keeping all other parameters constant found through literature [2]. By using this optimized intrinsic layer a - Si:H based p-i-n single junction solar cells were fabricated. Doped n and p-layers were deposited in another Hot-Wire CVD cluster tool with horizontal substrate-filament geometry. After the p-layer deposition in the cluster tool the film

was taken out to deposit intrinsic layer in the new vertical geometry reactor and again put back in cluster tool to deposit the n-layer. However, despite of an air break two times, an efficiency of 4.7 % has been achieved which clearly indicates device quality of the i-layer.

2. EXPERIMENTAL DETAILS

Intrinsic a - Si:H films were deposited by HWCVD process in single separate chamber on glass substrate (Corning 1737) for conductivity and Raman spectra analysis and p-type ⟨100⟩ crystalline silicon wafer for FTIR spectra analysis. Tantalum (Ta) filament with two wire arrangement is used as hot wire and kept constant at 1600 °C temperature. The substrate temperature was maintained at 200 °C. Pure silane (SiH_4) is used as a precursor gas with constant flow rate of 20 SCCM. The deposition pressure was varied from 15 mTorr to 25 during the deposition. The filament to substrate distance was kept at 6.5 cm with vertical substrate-filament geometry.

Film thickness was determined by Dektak II surface profilometer, from which the deposition rate was determined. Fourier transform infrared (FTIR) spectroscopy was used to measure bonding configuration in the a-Si:H films. The microstructure factor (R^*) and the hydrogen content was evaluated as per the accepted procedure [3]. Raman spectroscopy was performed to evaluate the structural properties in the a-Si:H films [4]. UV-Vis spectrophotometry was used for the evaluation of the band gap of the films. Dark and photoconductivity measurements of the films and I-V characteristic of the solar cells were measured with the help of Keithley 2400 Source meter and xenon arc lamp at 100 mW/cm^2 intensity. The power of xenon arc lamp was set to 100 mW/cm^2 by an AM 1.5 calibrated solar cell.



a b

Fig. 1 *– Photograph of single chamber HWCVD designed at our laboratory* (*a*), *Inside view of the chamber showing vertical substrate-filament assembly* (*b*)

3. RESULTS AND DISCUSSION

All intrinsic a-Si:H films deposited by HWCVD are found to be amorphous in nature as revealed from Raman spectra analysis. It has been observed that there is slight increase in the deposition rate from 7.2 Å/sec to 10 Å/sec with increase in deposition pressure from 15 mtorr to 25 mtorr [5]. The best a-Si:H film was obtained at lower chamber pressure with photoconductivity gain (σ_{ph}/σ_d) of 8.4×10^4. The good quality of the film can be attributed to increased mean free path of dissociated radicals at lower pressure and higher surface mobility of the ad-atoms on the substrate. This leads to better Si - Si and Si - H bonding configuration with minimum bulk defect states. The dark and photoconductivity values with different deposition rates are shown in the Table 1.

Table 1 – *Deposition rate and photoconductivity gain at different deposition pressure*

Sample	P (mtorr)	R_d (Å/sec)	σ_d (Ω^{-1}cm^{-1})	σ_{ph} (Ω^{-1}cm^{-1})	Photo-sensitivity
01	15	7.2	4.3×10^{-10}	3.6×10^{-5}	8.4×10^4
02	20	8.2	2.7×10^{-8}	2.3×10^{-4}	8.8×10^3
03	25	10	9.5×10^{-10}	3.1×10^{-6}	3×10^3

FTIR spectra of a - Si:H films deposited at different deposition pressure reflects that the film deposited at 15 mtorr pressure shows better device quality properties compared to films deposited at higher pressure. The peak at 1100 cm^{-1} indicates that there is still small amount of oxygen presence in the form of Si-O bond in the film. However this could be due to post oxidation of the film. A microstructure factor (R^*) was determined through FTIR spectra analysis and was found to be 0.4 and hydrogen content of about 8 % was observed.

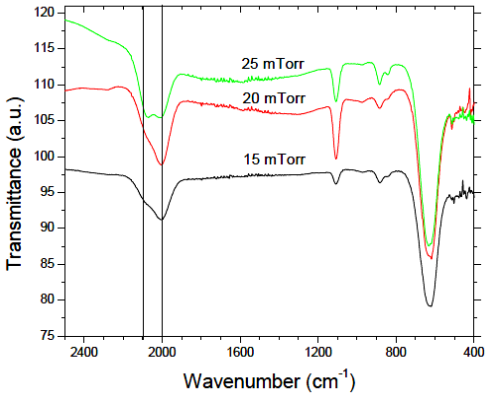


Fig. 2 – *FTIR spectra of films deposited by HWCVD at different deposition pressure*

The Raman spectra of the a-Si:H films are shown in Fig. 3. Si-Si TO like peak for all the films appears near 480 cm^{-1}, clearly indicating that all films are amorphous in nature. The I_{TA}/I_{TO} peak ratio is found to be 0.2 and bond angle deviation ($\Delta\theta$) is 6.7, as determined from the FWHM of the TO-like peak.

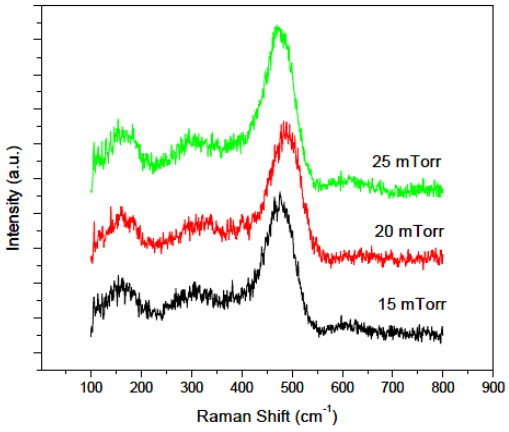


Fig. 3 – *Raman spectra of* a - Si:H *films deposited by HWCVD at different deposition pressure*

Further, a single junction p-i-n a - Si:H silicon solar cell with structure, glass/SnO_2:F (Asahi-U type TCO)/p-a-Si:H/i-a-Si:H/n-μc-Si:H was fabricated on 2 × 3 cm^2 area substrate with optimized parameters of intrinsic a - Si:H film. Al contacts of size 3 mm in diameter were deposited on top of the n-layer by thermal evaporation technique to complete the device. The overall thickness of the cell was 380 nm with n and p layer contributing about 40 nm in the configuration. No special light trapping

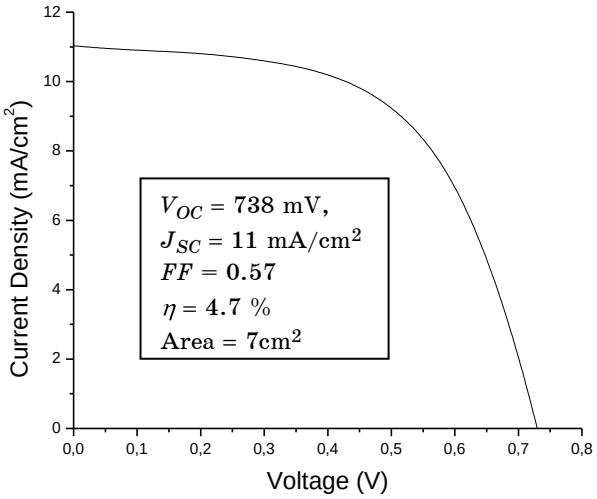


Fig. 4 – *I - V characteristic of fabricated single junction* a - Si:H *solar cell*

scheme was employed and commercial substrates were used with no further texturing [6]. We achieved an efficiency of 4.7 % (FF = 57 %, V_{oc} = 738 mV and J_{sc} = 11 mA) under AM 1.5 (100 mW / cm^2) illumination. I-V plot of solar cell is shown in the Fig. 4.

4. CONCLUSION

Intrinsic a-Si:H layers were deposited by hot-wire CVD technique in the newly developed reactor where the geometry is vertical, at different chamber pressures keeping other parameters constant. Device quality film has been found at lower deposition pressure of about 15 mtorr with deposition rate of 7.2 Å/sec and photoconductivity gain of about ~ 10^5. Further, a-Si:H single junction solar cell has been fabricated using this optimized intrinsic layer as absorber with air break during device fabrication. The conversion efficiency of 4.7 % was achieved under AM 1.5 illumination without applying any anti-reflection coating and light trapping schemes.

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