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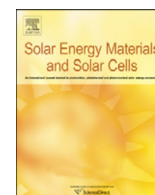

High deposition rate device quality a-Si:H films at low substrate temperature by HWCVD technique

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ABSTRACT

Hot wire chemical vapor deposition (HWCVD) provides a low cost fabrication technology for hyrdogenated amorphous silicon (a-Si:H) based thin film single junction and tandem solar cells. In this paper, we report our results on the high deposition rate device quality a-Si:H films deposited by HWCVD at low substrate temperature. Films have been deposited using tantalum filament with highest deposition rates of 16 Å/s and having the desired device quality properties like high photoconductivity gain ($\sigma_{ph}/\sigma_{dark}$), low microstructure factor (as revealed by IR spectroscopy), good short range order parameter and acceptable thickness uniformity over the deposited area. An average photoconductivity gain of $\approx 3\times10^5$ has been obtained for the films deposited at rates $\sim$15 Å/s and the substrate temperature of 200 °C. The p- and n-type films have also been deposited by the HWCVD. Single junction p–i–n solar cells on ASAHi U-type substrates, fabricated using these layers have an efficiency of 5.1% under AM1.5 illumination. Depositing anti-reflection coating on front side, reflection coating before back contact and using textured TCO layer for light trapping would further improve the efficiency of the cell.

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1. Introduction

Various techniques have been used to fabricate a-Si:H based single junction and tandem thin film solar cell devices. Recently, HWCVD [1,2] process has become a potential contender to replace the conventional plasma enhanced chemical vapor deposition (PECVD) process for the fabrication of these solar cells as HWCVD has the merits of high deposition rate, ion and electron free deposition atmosphere and a real possibility of large area up-scaling, which could lead to substantial reduction in the cost of production as there is no requirement of expensive RF power sources and matching networks. HWCVD has been carried out employing wires or filaments of various refractory metals. Thus tungsten, tantalum [3], rhenium, molybdenum and also graphite [4] have been used as filament material. The best choice of the filament is determined by its operational life for the deposition and deposited film quality.

Hydrogenated amorphous silicon solar cells have strategic advantage over CIGS and CdTe solar cells. The disadvantages of cadmium telluride cells lie in the very materials themselves. The heavy metal cadmium is toxic (as much like lead) and has the tendency to accumulate in the food chain. The metal tellurium is available in limited quantities, thus limiting supply and therefore leads to an increased cost. Similarly in case of CIGS solar cell time consuming and expensive batch-wise deposition techniques are used, partly forced by the complex phase diagram of $Cu(In,Ga)(S,Se)_2$. Indium resources are limited, which may result in difficulties in sustaining this technology. These limitations are not there in the case of hydrogenated amorphous silicon solar cell technology.

We know that cost reduction of the electricity generated by a solar cell is the important challenge in the field of thin film photovoltaics. Cost reduction is possible if device quality a-Si:H layers are deposited at high deposition rate on low cost substrates and at low substrate temperature. But it is well known that low pressure, medium silane flow rate, and higher substrate temperature are generally required to maintain device quality a-Si:H films [5]. It is also known that as we increase the deposition rate, the quality of material degrades in terms of its structure and optoelectronic properties. So we need to increase substrate temperature to maintain the device quality at high deposition rate. Thus Sheng et al. [5] have achieved a deposition rate of 68 Å/s with photosensitivity of 1.1×10^5 but at high substrate temperature of 350 °C. Nelson et al. [6] have deposited a-Si:H thin films at deposition rates up to 130 Å/s but again at high substrate temperature of 440 °C, and achieved conversion efficiencies of 5.5% at 18 Å/s, 4.8% at 35 Å/s, 4.1% at 83 Å/s and 3.8% at 127 Å/s .

2. Experimental details

Intrinsic a-Si:H films were fabricated by HWCVD process at substrate temperatures (T_s) ranging from 150 to 250 °C. All the

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other deposition parameters such as pure silane (SiH_4) flow rate of 20 sccm, pressure of 20 mTorr and filament temperature of 1600 °C were kept constant. We deposited a-Si:H films on n-type crystalline Si (1 0 0) for FTIR analysis and on glass substrate (Corning 1737) for Raman and UV–visible spectroscopy. Single junction p–i–n solar cells were fabricated on fluorine doped tin oxide (SnO_2:F-TCO) from Asahi, Japan. Films were deposited using both tungsten (W) and tantalum (Ta) filament under similar deposition conditions. Aluminum (Al) contacts were resistively evaporated for dark and light *I–V* measurement as well as back contact in the p–i–n solar cell.

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 [7]. Raman spectroscopy was performed to evaluate the structural properties in the a-Si:H films [8]. The I_{TA}/I_{TO} peak ratio and bond angle deviation $\Delta\theta$ were determined for the layers. 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 AM1.5 calibrated solar cell.

3. Results and discussion

Different filament materials have been used by researchers for carrying out HWCVD of a-Si:H films. We have used tungsten and tantalum filament for the deposition of a-Si:H films. First films were deposited using tungsten filament but it was observed that tungsten filament had a short operational life due to silicide formation and broke down after 4–5 h of total deposition. Then we used tantalum filament and observed that it not only has good operational life but also gives a high deposition rate compared to the tungsten filament while maintaining the device quality of the films (see Fig. 1). This has been explained by earlier workers to be due to the higher rate of silicide formation on the tungsten surface than on the tantalum [9]. On the basis of deposition time dependent measurements it was shown that an increase in silicon content in the tungsten filament continuously increased with time, while the silicon content in the tantalum filament saturates rather quickly [10]. The emissivity of Ta is expected to be lower than its silicide Ta_5Si_3 [11] and hydrogen atom

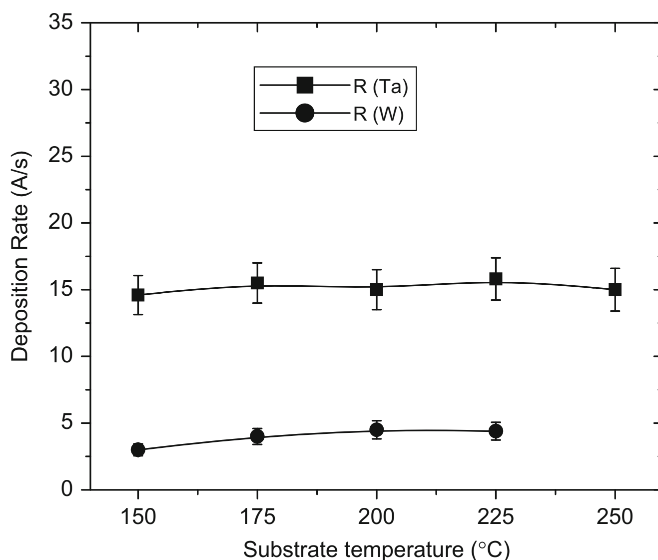

Fig. 1. Variation of the deposition rate of films deposited by HWCVD at different substrate temperatures using W and Ta filaments.

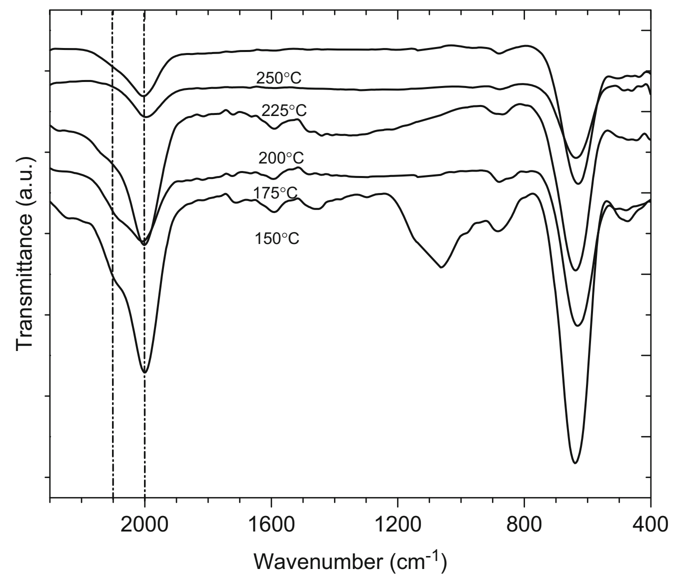

Fig. 2. FTIR spectra of films deposited by HWCVD at different substrate temperatures using Ta filament.

Table 1
Raman and FTIR analysis results of a-Si:H films deposited by HWCVD process at different substrate temperatures using Ta filament.

Sample no.	T_s (°C)	C_H (at%)	R^*	Γ_{TO} (cm^{-1})	$\Delta\theta$	I_{TA}/I_{TO}
1	150	7	0.4	58.9	7°	0.7
2	175	7	0.4	60.4	8°	0.6
3	200	4	0.3	56.2	7°	0.7
4	225	4	0.3	56.4	7°	0.7
5	250	4	0.2	61.4	8°	0.7

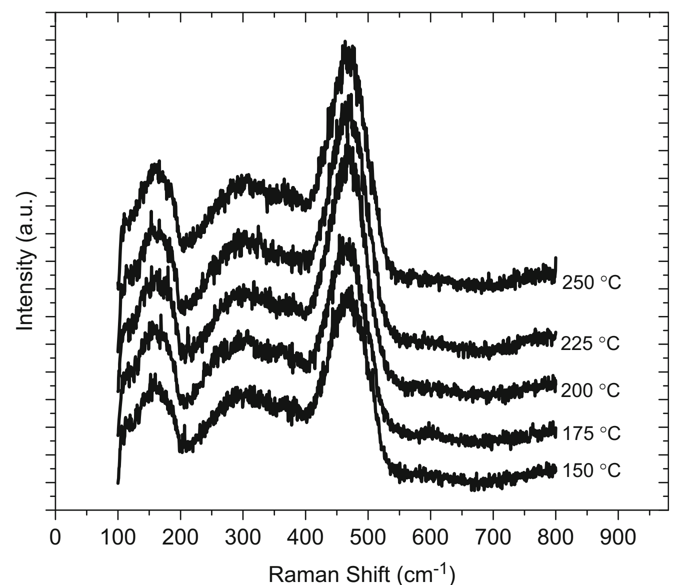

Fig. 3. Raman spectra of a-Si:H films deposited by HWCVD at different substrate temperatures using Ta filament.

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