Radical Flux Evaluation to Microcrystalline Silicon Films Deposited by Multi-Hollow Discharge Plasma CVD

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To evaluate radical fluxes for microcrystalline silicon film deposition, Si films were deposited in a combinatorial way using a multi-hollow discharge plasma CVD method. Film crystallinity varied with the distance from the powered electrode. Based on the film deposition rate and Raman crystallinity, we proposed a method to estimate hydrogen flux. This evaluation of hydrogen flux is one of useful way to understand a process window of μc-Si:H films.

1. Introduction

Microcrystalline silicon(μc-Si:H) films have attracted much attention as materials of the bottom-cells in Si thin film tandem photovoltaics [1]. However, the deposition rate of μc-Si:H is very low due to the low SiH₄ density under relatively low partial pressure conditions using Plasma Enhanced Chemical Vapor Deposition (PECVD). Even though high pressure depletion regime has been proposed as an alternative deposition method to overcome above difficulties [2], a narrow process window which determined by H and Si radical flux makes it difficult to fabricate device quality microcrystalline silicon films.

In this study, Si films were deposited in a combinatorial way using a multi-hollow discharge plasma CVD method. We present a new approach to flux evaluation, by which we discuss a process window of μc-Si film deposition.

2. Experimental

A multi-hollow discharge plasma CVD reactor consists of one powered electrode and a pair of grounded electrodes to generate plasma as shown in Fig. 1[3].

The silane dilution ratio \( R=(\text{[H}_2]+\text{[SiH}_3])/\text{[SiH}_4] \) was kept at 300. The total pressure and gas flow rate were sustained at 2Torr and 150sccm, respectively. The substrate holder was set vertically on the powered electrode to obtain information on spatial distribution of deposition radicals. The substrate temperatures \( (T_s) \) were varied from RT to 250°C. Crystallinity \( (\chi_C) \) was determined with a Raman spectroscope (Jasco, NRS-3100). Deposition rate \( (R_d) \) was obtained as film thickness divided by deposition time.

3. Experimental results and discussion

Figure 2 shows (a)\( R_d \) and (b)\( \chi_C \) as a function of the distance from the electrode \( l \), respectively. The \( R_d \) of each film in Fig. 2 (a) decreases exponentially with \( l \) for \( l>5 \text{ mm} \) because SiH₄ density, which is the main deposition precursor for high-quality films, decreases exponentially with \( l \) due to their loss at the surfaces of reactor wall. The \( \chi_C \) in Fig. 2 (b) is higher near the discharge region and drops sharply.
in the crystalline/amorphous transition region around $l=20-40$mm.

![Graph showing deposition rate and crystallinity](image)

Fig.2. Dependence of (a) deposition rate and (b) crystallinity $X_C$ on the distance from the electrode $l$.

To obtain further information on the contribution of each flux to film deposition near the discharge region, SiH$_3$ flux ($\Gamma_{Si} = nv_{Si}/4$) was deduced using the following equation [4]:

$$R_d(SiH_3) = \frac{M_{Si}}{N_A \rho_{Si}} \left( \frac{nv_{Si}}{4} \right) \left( 1 - \frac{1 + A_S^2}{\sqrt{1 + A_S^2}} \right)$$

(1)

where $R_d$ is deposition rate, $M_{Si} = 28.09$ g/mol of the atom molar mass, $N_A = 6.02 \times 10^{23}$ /mol of the Avogadro number, and $\rho_{Si} = 2.2$ g/cm$^3$ the film specific gravity. The sticking probability $s$ and the surface reaction probability $\beta$ of SiH$_3$, being the predominant deposition precursor, were 0.1 and 0.28, respectively.

To determine $\Gamma_{Si}$, we considered $R_d$ of only a-Si:H region, and extrapolated towards the $\mu$-c-Si:H region as $\Gamma_{Si}$ of $\mu$-c-Si region as shown in Fig.3 (a) because the $R_d$ of $\mu$-c-Si region is determined by the balance between deposition due to $\Gamma_{Si}$ and etching due to $\Gamma_H$ whereas a-Si:H region is predominantly by deposition due to $\Gamma_{Si}$. Figure 3 (b) shows a flux ratio of H atoms to SiH$_3$ radicals estimated using the relationship between $\Gamma_H/\Gamma_{Si}$ and $X_c$ reported by S. Nunomura, et al.[5]. Figure 3 (c) shows $l$ dependence of H atom flux estimated using $\Gamma_{Si}$ in Fig. 3(a) and $\Gamma_H/\Gamma_{Si}$ in Fig. 3(c). $\Gamma_H$ decreases with increasing $l$ and the gradient of $\Gamma_H$ becomes sharper with decreasing $T_S$.

At high substrate temperature $T_S$ is high near the electrode region resulting in widening the high crystallinity region. These results show that the increase of $T_S$ is one possible way to obtain a wide process window of $\mu$-c-Si:H films.

![Graph showing dependence of deposition rate and ratio of H atoms to SiH$_3$](image)

Fig.3. Dependence of (a)$\Gamma_{Si}$, (b)$\Gamma_H/\Gamma_{Si}$ and (c)$\Gamma_H$ on the distance from the electrode $l$.

4. Conclusion

Si thin films were deposited in a combinatorial way using the multi-hollow discharge plasma CVD method. Based on the film deposition rate and Raman crystallinity, we proposed the method to estimate hydrogen flux. This evaluation of hydrogen flux is one of useful way to understand a process window of $\mu$-c-Si:H films.

References