Linear and Nonlinear Correlation between Deposition Rate and SiH Emission Intensity in SiH_4 Multi-hollow Discharge Plasmas

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To realize stable a-Si:H solar cells against light exposure, suppressing cluster incorporation into a-Si:H films is important, because incorporation of clusters leads to light degradation of a-Si:H films. To reduce the fabrication cost, a high deposition rate is also required. Here, we studied correlation between deposition rate and SiH emission intensity in SiH_4 multi-hollow discharge plasmas, and found the amount of clusters in plasma affects the correlation. Eventually, we found a condition for a high deposition rate and a low cluster incorporation amount at the same time.

1. Introduction

High rate deposition of high quality hydrogenated amorphous silicon (a-Si:H) films is required for a-Si:H solar cell fabrication in industry [1-4]. Increasing the deposition rate, which is often realized by increasing the discharge power, generally causes deterioration of a-Si:H film properties. We have found that incorporation of a-Si:H nanoparticles below 10 nm in size (clusters) into films is responsible for light induced degradation of a-Si:H films [5]. Based on the results, we have developed a multi-hollow discharge plasma CVD method to suppress incorporation of clusters into films, resulting in depositing highly stable a-Si:H films [6]. For the method, gas flow is the key to suppressing cluster incorporation. The gas is introduced from the deposition region to the discharge region, and films are deposited in the upstream region. Clusters generated in the discharge are transported toward the downstream region by the gas flow, suppressing cluster incorporation into films deposited in the upstream region.

We also have developed a real-time monitor of the cluster volume fraction in films by employing three quartz crystal microbalances (QCMs) [7]. The method provides information on amount of clusters incorporated into films as well as deposition rate, $DR_{radical}$, due to SiH_3 which is the main precursor for high quality films [8-11].

Here we studied correlation between deposition rate and SiH emission intensity in multi-hollow discharge CVD plasmas, and found the amount of clusters in plasma affects the correlation. We found a condition for a high deposition rate and a low cluster incorporation amount at the same time.

2. Experimental

Experiments were performed using a multi-hollow discharge plasma CVD reactor equipped with the QCMs as shown in Fig. 1. The gas was introduced from a gas inlet ring set below the multi-hollow electrodes and evacuated by the vacuum system located at the upper side of the electrodes. The gas flow velocity of SiH_4 was 18.4 - 129 cm/s. The pressure was kept at 0.5 Torr. The discharge frequency was 60 MHz. The discharge power density was 0.6 - 3.0 W/cm^3. The QCM system was set in the upstream region. Figure 2 shows a schematic of the QCM system. Channel A

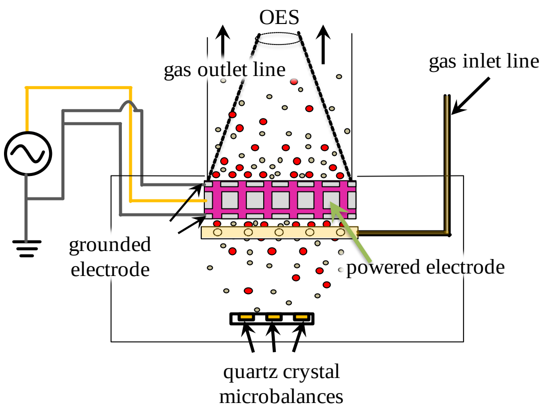

Fig. 1 Multi-hollow discharge plasma CVD reactor with QCMs.

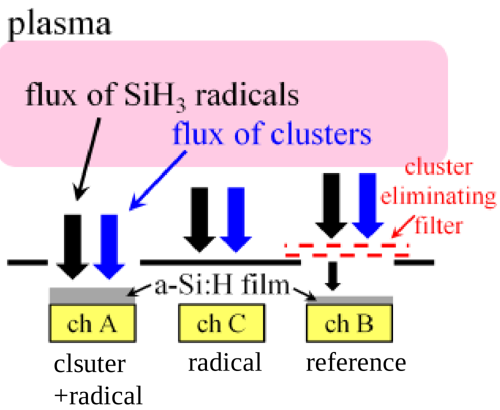

Fig. 2. Configuration of three QCMs.

was used for measuring the deposition rate DR_{total} due to SiH_3 radicals and clusters. Channel B was applied to measure the deposition rate $DR_{radical}$ due to SiH_3 radicals by using the cluster eliminating filter [12]. The filter eliminates the contribution of the clusters to the deposition of films, because the sticking probability of the clusters and the surface reaction probability of the radicals are 100% and 30%, respectively. Channel C was used as a reference sensor, because the resonance frequency of quartz crystal depends on temperature and pressure. We employed the ratio $R=DR_{total}/DR_{radical}$ as an indicator of the amount of clusters incorporated into films.

To obtain information on the generation rate of SiH_3 radicals due to electron impact dissociation of SiH_4, optical emission intensity of SiH 414nm was measured with a spectrometer (Ocean Optics, USB2000).

3. Results and discussion

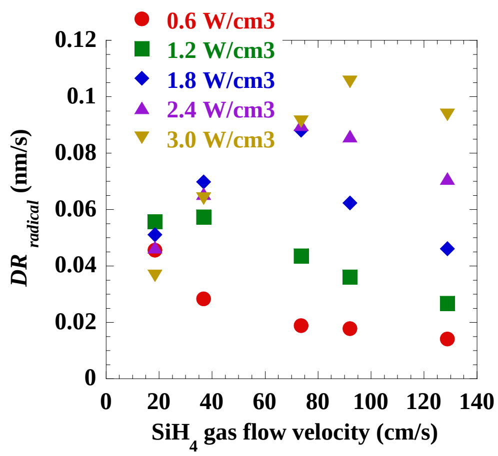

Fig. 3. Dependence of $DR_{radical}$ on SiH_4 gas flow velocity as a parameter of discharge power density.

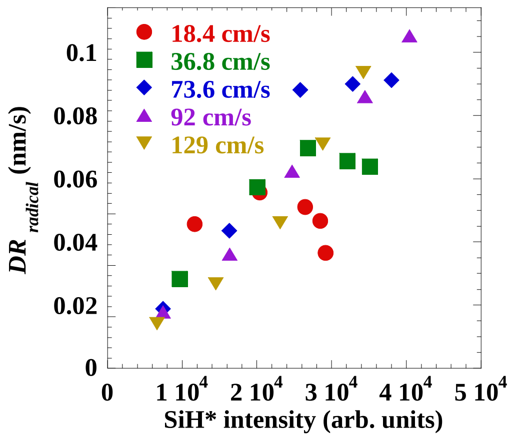

Fig. 4. Correlation between $DR_{radical}$ and SiH intensity as a parameter of gas flow velocity.

Figure 3 shows dependence of $DR_{radical}$ on the gas flow velocity as a parameter of discharge power density. $DR_{radical}$ decreases with increasing the gas flow velocity in the low power regime ≤ 1.2 W/cm^3, whereas it increases up to a certain SiH_4 gas flow rate in the high power regime ≥ 1.8 W/cm^3.

Figure 4 shows the correlation between $DR_{radical}$ and SiH intensity. $DR_{radical}$ is nearly proportional to SiH intensity. However, in low gas flow velocity and high SiH intensity (high discharge power) region, $DR_{radical}$ decreases with increasing SiH intensity. These results suggest that radical transport efficiency to substrate decreases with increasing SiH intensity in this region, that is, radical loss rate increases. This is probably because many clusters exit in plasma and absorb radicals. As a result, there is a good condition for high $DR_{radical}$, and low amount of cluster incorporation.

4. Conclusion

We studied correlation between deposition rate and SiH intensity in SiH_4 multi-hollow discharge plasmas, and found that many clusters in plasmas increase the loss rate of SiH_3 radicals in low gas flow velocity and high SiH intensity region.

Acknowledgements

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References

[1] T. Matsui, et al., Prog. Photovolt: Res. Appl. (2012) DOI: 10.1002/pip.2300.
[2] Y. Watanabe, et al., App. Phys. Lett. **53** (1988) 1263.
[3] M. Shiratani, et al., IEEE Trans Plasma Sci. **22** (1994) 103.
[4] T. Nishimoto, et al., J. Non-Cryst. Solids **299** (2002) 1116.
[5] K. Koga, et al., Jpn. J. Appl. Phys. **41** (2002) L168.
[6] K. Koga, et al., Jpn. J. Appl. Phys. **44** (2005) L1430.
[7] Y. Kim, et al., Jpn. J. Appl. Phys. **152** (2013) 01AD01.
[8] S. Toko, et al., J. Phys.: Conf. Ser. **518** (2014) 012008.
[9] Y. Hashimoto, et al., J. Phys.: Conf. Ser. **518** (2014) 012007.
[10] S. Toko, et al., Thin Solid Films (2015) doi:10.1016/j.tsf.2015.02.052.
[11] W. M. Nakamura, et al., Surf. Coat. Technol. **205** (2010) S241.
[12] K. Koga, et al., Rev. Sci., Instrum. **76** (2005) 113501.