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Effects of Pressure on Characteristics of a-Si:H Films Desorbed using Multi-Hollow Discharge Plasma CVD

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In recent years, power supply for the “Internet of Things” devices has been one of the major concerns limiting the expansion of the IoTs technology [1]. Hydrogenated amorphous silicon (a-Si:H) solar cell is a good candidate for the IoT power source due to the flexibility and low manufacturing cost. The light-induced degradation is one of the most important issues of the cells. SiH₄ plasma chemical vapor deposition (CVD) is a major process for a-Si:H film deposition. Amorphous silicon nanoparticles below 10 nm in size (clusters) and higher-order silane molecules (HOSs) are generated in the plasmas. They are incorporated into films leading to an increase of Si-H₂ bond density in films which is correlated with the light-induced degradation. So far, we have succeeded in fabricating highly stable a-Si:H films using a multi-hollow discharge plasma CVD (MHDPCVD) method which can reduce cluster incorporation using fast gas flow [2,3]. The gas pressure is an important parameter which affects the generation of SiH₃ radicals, HOSs and clusters. For the low pressure conditions, the multi-hollow discharge plasmas tend to expand from discharge region toward deposition region in which the gas flow is slow, leading to the cluster incorporation into films. Here we study effects of the gas pressure on the film qualities such as the density ratio $I_{\text{SiH}_2}/I_{\text{SiH}}$ of Si-H₂ bonds and Si-H bonds in films.

The deposition experiments were carried out using the MHDPCVD with the cluster-eliminating filter [2]. The substrate temperature was kept at 170 °C. SiH₄ was fed from the bottom of the reactor at 126 sccm. 110 MHz discharge voltage of 20 W was applied to the power electrode. The total pressure was 0.08-0.25 Torr. To measure the $I_{\text{SiH}_2}/I_{\text{SiH}}$, a-Si:H films deposited in the upstream region from the electrode were measured with a Raman spectroscope [3].

Figure 1 shows dependence of $I_{\text{SiH}_2}/I_{\text{SiH}}$ on gas pressure. The $I_{\text{SiH}_2}/I_{\text{SiH}}$ is 0.087 for the pressure of 0.08 Torr. It decreases to 0.062 for 0.15 Torr then increases to 0.082 for 0.25 Torr. To explore the cause of the change in trend, we did surface morphological analysis by AFM. Figure 2 displays pressure dependence of RMS roughness of the deposited films which shows the same tendency compared with the dependence of $I_{\text{SiH}_2}/I_{\text{SiH}}$. The increase of the RMS roughness suggests the nanoparticle incorporation into films. From photo images, the plasma region extends into the upstream region from the discharge region with decreasing the pressure. The plasma expansion might bring about the increase of flux of nanoparticles generated in plasmas in the upstream region, resulting the increase

of $I_{\text{SiH}_2}/I_{\text{SiH}}$ and RMS roughness from 0.15 Torr to 0.08 Torr. The gas residence time increases with the pressure. Nanoparticles grow by deposition of SiH_x radicals and/or coagulation during the transport toward the substrate. For the pressure from 0.15 to 0.25 Torr, nanoparticles might grow due to the increase of gas residence time, leading to the increase of $I_{\text{SiH}_2}/I_{\text{SiH}}$ and RMS roughness. These results indicate that selecting an appropriate pressure is the key to reduction of Si-H₂ bonds in films.

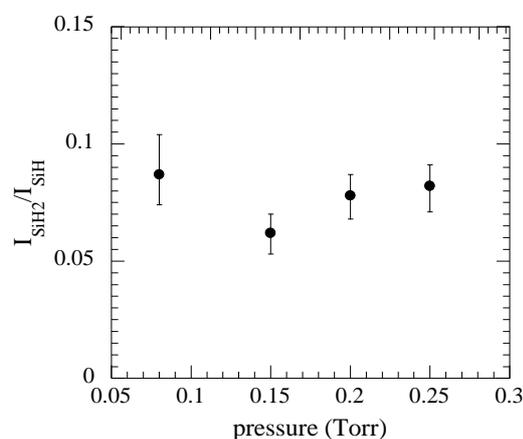
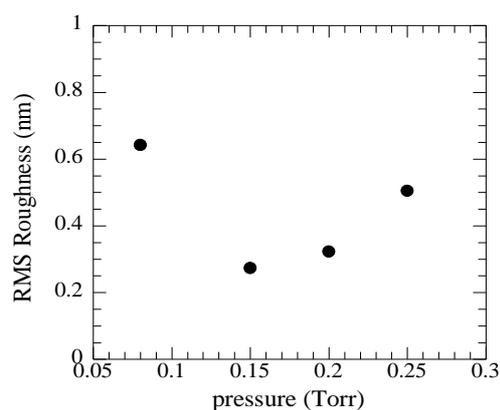
Fig. 1. Pressure dependence of $I_{\text{SiH}_2}/I_{\text{SiH}}$ of a-Si:H films.

Fig. 2. Dependence of Roughness on pressure

[1] A. Raj and D. Steingart, J. Electrochem. Soc. **165**, B3130 (2018).[2] S. Toko, et al., Thin Solid Films **587**, 126 (2015).[3] K. Keya, et al., Jpn. J. Appl. Phys. **55**, 07LE03 (2016).