1. Introduction

Thin film hydrogenated amorphous silicon (a-Si:H) solar cells have several advantages over other solar cells, such as low cost, flexible and lightweight features. They are, therefore, promising to be a power source for the “Internet of Things” devices. One of the important issues is to use a-Si:H solar cells for IoT devices in suppression of light-induced degradation. By Raman spectroscopy, we have succeeded in detecting Si-H bonds in cells which are responsible for the light-induced degradation [1, 2]. A-Si:H solar cells are most commonly fabricated using SiH4 plasmas. Incorporation of clusters and higher-order silane (HOS) molecules formed in the plasmas is the main origin of Si-H2 bonds in films [3]. We significantly reduce such clusters and HOS molecules incorporation by adopting the multi-hollow discharge plasma CVD (MHDPCVD) method together with a cluster eliminating filter [4]. Therefore, the films still contains many Si-H2 bonds. Here, we report a deposition method that further suppresses clusters and HOS molecules incorporation.

2. Experimental

We deposited undoped a-Si:H films (I-layer) on B-doped Si films (P-layer) by the MHDPCVD method with the cluster eliminating filter. Pure SiH4 gas fed into the reactor at 84–147 sccm. The total pressure was 0.08 Torr. The discharge frequency and power were 110 MHz and 20 W respectively. The substrate temperature was 170 °C. The thickness of I-layer was 20 nm. Measurements of the I$_{S_{190}}$/I$_{S_{191}}$ ratio were carried out with a Raman spectroscope (JASCO, NRS-3100) equipped with a HeNe laser (λ = 632.8 nm). The scan time was 100 s and the cumulative number of measurement was 3 times. The diameter of the probe laser was 1 μm. We deconvoluted Raman spectra around 2000–2090 cm$^{-1}$ of a-Si:H films into two peaks corresponding to Si-H bonds (2000 cm$^{-1}$) and Si-H2 bonds (2090 cm$^{-1}$) and eventually obtained I$_{S_{190}}$/I$_{S_{191}}$ [5].

3. Results and discussion

In order to investigate more suitable film deposition conditions, we have evaluated the SiH4 gas velocity and diffusion velocity of clusters and HOS molecules. First, we derive the gas residence time $\tau_{g}$ as follows:

$$\tau_{g} = \frac{z}{n_{g}} = 1.11 \times 10^{4} \times \frac{1}{FR},$$

where $n_{g}$ is the number of gas molecules in hollows, $n_{c}$ is the number of the molecules supplied to the hollow per second and $FR$ is SiH4 gas flow rate. SiH4 gas velocity $v_{g}$ is expressed as follows:

$$v_{g} = \frac{z}{\tau_{g}} = 1.8 \times FR,$$

where $z$ is the hollow length. In addition, diffusion velocity of clusters and HOS molecules $v_{d}$ is expressed as follows:

$$v_{d} = \frac{D}{A},$$

where $D$ is diffusion coefficient and $A$ is characteristic diffusion length. Figure 1 shows the relation between gas velocity and diffusion velocity. For 84 sccm, gas velocity is 15.1 m/s and clusters above 0.5 nm can be driven to downstream region. For 147 sccm, gas velocity is 26.5 m/s and HOS molecules above 0.36 nm can be driven to downstream region. By increasing the SiH4 gas velocity from 15.1 to 26.5 m/s, we succeeded in suppressing incorporation of HOS molecules into the films. Eventually, I$_{S_{190}}$/I$_{S_{191}}$ decreased to one third at 26.5 m/s as compared with that at 15.1 m/s.

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References