Measurements of SiH_4/H_2 VHF Plasma Parameters with Heated Langmuir Probe

Tsukasa Yamane [1], Sachiko Nakao[1], Yoshiaki Takeuchi [1], Hiroshi Muta [2], Ryuta Ichiki[3], Kiichiro Uchino[2] and Yoshinobu Kawai [2]

[1] Solar Power Department, Mitsubishi Heavy Industries Ltd., Isahaya, Nagasaki, 854-0065, Japan
[2] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga, Fukuoka 816-8580, Japan
[3] Department of Electrical and Electronic Engineering, Oita University, Oita, 870-1192, Japan

E-mail: kawai@aees.kyushu-u.ac.jp

Abstract
The parameters of S_iH_4/H_2 VHF plasma were measured as a function of silane gas concentration with a heated Langmuir probe. When the sailane gas concentration was increased, the nagative ion density increased. The negative ion density was estimated from the reduction of the electron saturation current. In addition, the dependence of the sheath potential on the silane gas concentration agreed with the theoretical values derived from the Bohm sheath equation including negative ions.

Keywords VHF plasma, negative ions, silicon thin film, sheath potential, multi-rod electrode

1. Introduction

Microcrystalline silicon has been widely investigated using VHF plasmas in order to reduce production costs of silicon thin film solar cells [1]. Recently, higher deposition rate of microcrystalline silicon was achieved by a short gap discharge at high pressure [2-4]. Microcrystalline silicon is deposited by introducing a small amount of SiH_4 gas into H_2 plasmas. As well known, negative ions are produced in S_iH_4 plasma [5]. The cross section of electron attachment is much lower than that of ionization. However, negative ions are confined in plasma without diffusing to electrodes, leading to high negative ion density. Thus, it is an important subject in solar cell development to investigate S_iH_4/H_2 plasma parameters including negative ions. The simplest method to estimate the negative ion density is to use Langmuir probe characteristics. The negative ion density n_- normalized to the ion density n_+ is in the following:

$$n_-/n_+=1-I_{es}/I_{es0} \qquad (1)$$

where I_{es} and I_{es0} is the electron saturation current with negative ions and without negative ions, respectively. Thus, the negative ion density is easily estimated from the reduction of the electron saturation current. Note that this method includes the assumption that the ion density is kept constant even when negative ions increase [6].

The sheath potential is one of key parameters in plasma CVD because it corresponds to ion bombardment energy. According to the Langmuir probe theory [7], the sheath potential V_w is in the following

$$V_w \approx \frac{\kappa T_e}{2q}\ln\left(\frac{2M_+}{\pi m}\right) \qquad (2)$$

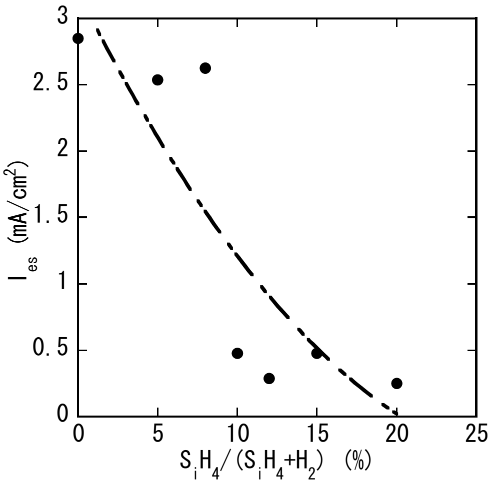
Here κ, q, m and M_+ is Boltzman constant, electron charge, electron mass and ion mass, respectively. As seen from Eq. (2), the sheath potential is estimated from the electron temperature Te if there are not negative ions. That is, the comparison between measured sheath potentials and those calculated using Eq. (2) provides information about existence of negative ions. In this paper, we measured the parameters of VHF S_iH_4/H_2 plasma with a heated Langmuir probe and discussed the VHF S_iH_4/H_2 plasma characteristics from the Langmuir probe *I-V* curve. We found that there are a lot of negative ions in SiH_4/H_2 VHF plasma.

2. Experimental

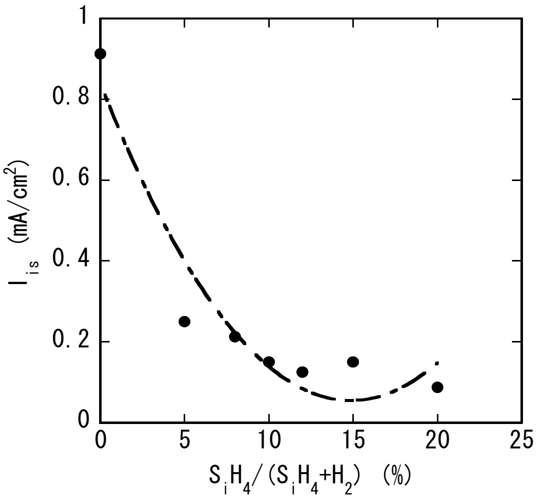
The experimental apparatus consisted of a stainless steel vacuum vessel (height: 420 mm, width: 1350 mm, depth: 470 mm), a multi rod electrode [8] of 1200 mm x 114 mm and a VHF power supply. The distance between the multi rod electrode and the glass substrate was 34 mm, where a punched electrode (stainless- steel- disk plate) of 1200 mm x 114 mm was used as a substrate holder to look at plasma uniformity. The VHF power source with frequency of 60 MHz was used and the power was150 W, where we used a balanced power feeding method [9] to produce a stable VHF plasma. Here the forward and reflected RF power was measured with a power meter. The gas flow rate was 50-150 sccm. The plasma parameters were measured with a heated Langmuir probe [10]. In order to reduce the disturbance of the Langmuir probe to the plasma, a tungsten wire of 0.3 mm in diameter was used as the heated Langmuir probe. Before measuring S_iH_4/H_2 VHF plasma parameters, the current range not disturbing plasma generation due to heating was confirmed and calibration for the surface area of the heated probe was performed by measuring argon and hydrogen plasma using an ordinary Langmuir probe.

3. Experimental results and discussion

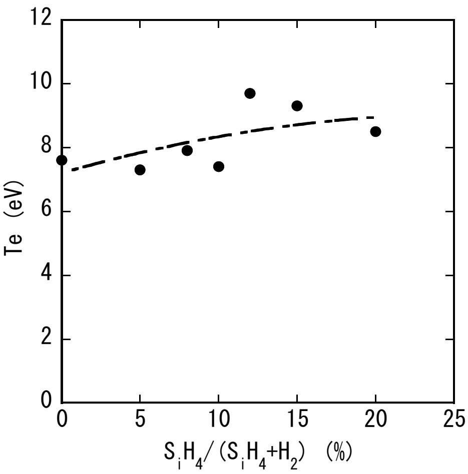
We produced a VHF S_iH_4/H_2 plasma and measured the plasma parameters as a function of silane gas concentration (=$[SiH_4]/[S_iH_4]+[H_2]$) for 500 mTorr. The results are shown in Fig.1 It was found that both the ion saturation current I_{is} and the electron saturation current I_{es} decrease with increasing S_iH_4 gas. On the other hand, the electron temperature Te tends to increase when $[S_iH_4]/[S_iH_4]+[H_2]$ is increased. Here we estimated the negative ion concentration n_-/n_i from Eq. (1) for different gas flow rates. Fig. 2 indicates that when the silane gas concentration is increased, the negative ion concentration rapidly increases and tends to saturate at a certain silane gas concentration. This is consistent with the increase of the electron temperature, that is, Te begins to increase when negative ions are produced.



(a)



(b)



(c)

Fig. 1 Plasma parameter measurements: (a) the electron saturation current, (b) the ion saturation current and (c) the electron temperature.

Fig. 3 shows the dependence of the sheath potential on silane gas concentrations. Here the solid lines are the theoretical sheath potentials calculated using the sheath equation derived by Shindo and Horiike [11]:

$$n_e \exp(-\frac{eV}{kT_e})(\frac{kT_e}{2\pi m})^{1/2} + n_- \exp(-\frac{eV}{kT_-})(\frac{kT_-}{2\pi M_-})^{1/2} = \{\frac{2(kT_+ + eV_B)}{M_+}\}^{1/2}\{n_e \exp(-\frac{eV_B}{kT_e}) + n_- \exp(-\frac{eV_B}{kT_-})\} \quad (3)$$

$$n_e \exp(-\frac{eV_B}{kT_e})\{\frac{1}{kT_e} - \frac{1}{2(kT_+ + eV_B)}\} + n_- \exp(-\frac{eV_B}{kT_-})\{\frac{1}{kT_-} - \frac{1}{2(kT_+ + eV_B)}\} = 0 \quad (4)$$

Here n_e and V_B is the electron density and the Bohm criterion voltage, and T_+ and T_- is the temperature of ions and negative ions, respectively. In this calculation, we assumed $T_+=T_-$. Note that there are theoretically two solutions [11]. The comparison between the experimental results and the theoretical ones indicates qualitative agreement.

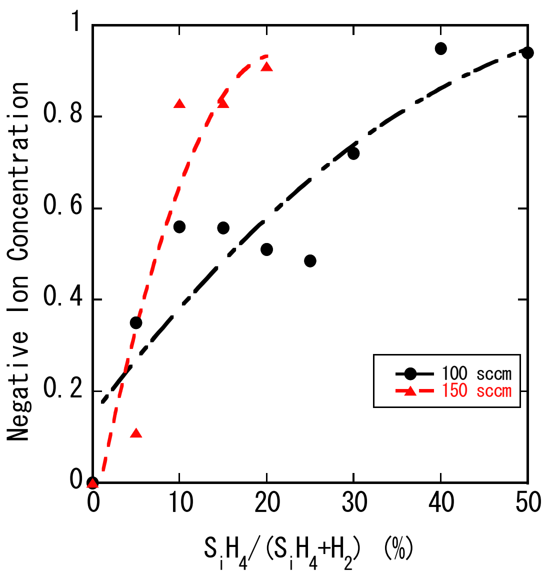


Fig. 2 Negative ion concentration.

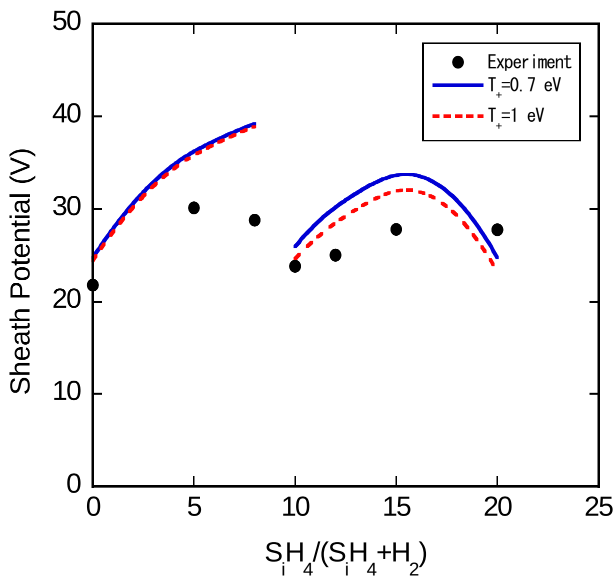


Fig. 3 Sheath potentials.

Fig. 1(b) shows that the ion saturation current decreases when the silane gas is increased. As well known, when there are negative ions, the sheath thickness becomes broad and as a result the ion saturation current decreases [12]. Thus, the observed reduction of the ion saturation current is understood by the change of the sheath thickness.

4. Conclusion

We measured the plasma parameters of S_iH_4/H_2 VHF plasma as a function of silane gas concentration with a heated Langmuir probe and estimated the negative ion density from the reduction of the electron saturation current. It was found that observed sheath potentials agree qualitatively with the theoretical values calculated using the sheath equation derived by Shindo and Horiike [11].

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