Sheath Potential Measurements in Negative Ion Plasma

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The sheath potential in a negative ion plasma was measured with the Langmuir probe and compared with the theory including negative ions, where the negative ion plasma was produced by introducing SF_6 gas into an Ar double plasma. The negative ion concentration was estimated from the reduction of the electron saturation current of Langmuir I-V curves. It was found that observed sheath potentials agree with theoretical values.

Microcrystalline silicon has been widely investigated to reduce the production cost of solar cells [1], where large area deposition (> $1m^2$) is also required. Recently, higher deposition rate of microcrystalline silicon has been achieved by a short gap discharge at high pressures [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 SiH_4 plasma [5]. The cross section of electron attachment is much lower than that of ionization. On the other hand, negative ions are confined in plasma without diffusing to discharge electrodes, leading to high negative ion density. Thus, it is one of important subjects to study the plasma characteristics of SiH_4/H_2 plasma in fabrication of microcrystalline silicon. In fact, anomalous reduction of the electron saturation current was observed in SiH_4/H_2 VHF plasma [6], suggesting the existence of negative ions.

The simplest method to estimate the negative ion density is to use Langmuir probes. The negative ion density n_- normalized to the ion density n_i , the negative ion concentration, is in the following:

$$\frac{n_-}{n_i} = 1 - \frac{I_e}{I_{eo}} \qquad (1)$$

where I_e and I_{e0} is the electron saturation current with negative ions and without negative ions, respectively. Thus, the negative ion concentration is easily estimated from the reduction of the electron saturation current.

Charged particle species in plasma are measured with a quadorapole mass spectrometry (QMS). However, in the case of high pressures, QMS spectrum shows only the indication of particle species because of short mean free paths. Thus, we have proposed the sheath potential method to estimate the plasma characters. According to the Langmuir probe theory, the sheath potential V_w is in the following:

$$V_w \approx \frac{\kappa T_e}{2q} \ln\left(\frac{2 m_i}{\pi m_e} \right) \qquad (2)$$

Here κ, q, m_e and m_i is Boltzman constant, electron charge, electron mass and ion mass, respectively. As seen from Eq. (2), when the sheath potential and the electron temperature T_e are known, we can estimate dominant ion species. In addition, when there are negative ions, Eq. (2) is modified [7]. Thus, the sheath potential provides interesting information about a negative ion plasma. Here, we present the experimental results on the sheath potential in SF_6/Ar plasma as a test case about SiH_4/H_2 plasma since dominant ions are Ar^+ independent of the concentration of SF_6/Ar [8].

The experiments were performed using a DP device. The diameter and length of the stainless steel vacuum chamber were 500 mm and 1000 mm, respectively. Ar and SF_6 gas was introduced into the chamber with the mass flow controllers, separately. A 6-mm-diam planar Langmuir probe was used to measure the plasma parameters. The probe surface was cleaned periodically using ion bombardment in pure Ar plasma. Mass spectra of positive and negative ion species were analyzed with the QMS (Hiden EQP-500).

A SF_6/Ar double plasma was produced and charged particles were measured as a function of SF_6/Ar with the QMS. Here Te=0.2 -0.3 eV and the plasma density was around 10^{15} m^{-3}. The QMS spectra showed that dominants ions and negative ions are Ar^+ and F^-, respectively. Fig.1 shows the dependence of the sheath potential on the negative ion concentration,n_-/n_i, where the negative ion concentration was estimated using Eq. (1). As seen in Fig.1, when the negative ion concentration increases, the sheath potential decreases. The solid lines in Fig. 1 show the theoretical sheath potential for different electron temperatures that was calculated using the sheath equations derived by Shindo and Horiike [9]. As described in Ref. (9), the sheath potential is sensitive to the ion temperature T_i and the negative ion temperature T_-. In this calculation, T_i=T_-=0.03 eV was assumed. Fig. 1 indicates that the experiment agrees with the theory. Thus, we conclude that the sheath potential measurement using the Langmuir probe is a powerful method to obtain information about negative ions. We will apply this method to study the characteristics of SiH_4/H_2 VHF plasma. When there are negative ions in plasma, the ion saturation current decreases because the sheath width broadens out [7-9]. In this experiment, the tendency that the ion saturation current decrease against the negative ion concentration was observed. More detailed discussions about the sheath structure in a negative ion plasma will be necessary for the comparison between the experiment and the theory.

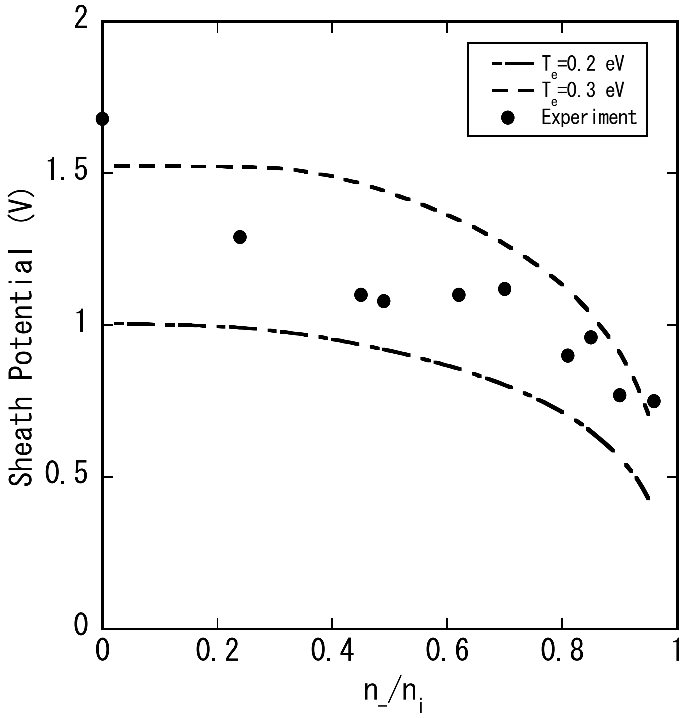

Fig. 1:The dependence of the sheath potential on the negative ion density normalized to the ion density, n_-/n_i. Here, the pressure and the flow rate of Ar gas is $4x10^{-4}$ Torr and 8 sccm, respectively.

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