LOSS PROCESS OF NEGATIVE CHARGES IN He+SF$_6$ AFTER-GLOW PLASMA IN PULSE MODULATED RF DISCHARGE

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The loss process of negative charges in pulse modulated radio frequency (rf, 13.56MHz) discharges containing SF$_6$ in He gas has been investigated experimentally using a Langmuir probe. It was found that the decay time of negative charge current collected into the probe decreased with adding the SF$_6$ fraction in He gas, whereas the density ratio of negative ions to electrons increased in the after-glow plasma. The quick drop of the plasma potential was obtained just after turning off the rf voltage, leading to the apparent increase in the electron density.

1. Introduction

Radio frequency (rf,13.56MHz) discharge plasmas in electronegative gases (such as SF$_6$, CF$_4$) are widely used for dry etching processes in electronics industries. It has been reported that negative ions in the rf plasmas affected a dry etching process. However, only few study has been done on behavior of negative ions in plasmas[1-5] because of the difficulty of a negative ion detection. The rf discharges in electronegative gases have inherent features different from electropositive discharges, such as the existence of a double layer near the powered electrode, nonzero electric field in the plasma, narrower sheaths and so on.

In the present work, the loss process of negative ions in rf plasma has been experimentally studied by modulating a rf discharge containing SF$_6$ in He gas into repetitive pulses. The negative ion component of negative charge density was observed to increase in the after-glow plasma process with decreasing the charged particle density.

2. Experimental System

Schematic diagram of the experimental apparatus is shown in Fig.1. The experiments were performed in a cylindrical vacuum chamber with a diameter of 16cm and length of 20cm. The He gas containing SF_6 or Ar was fed into the chamber at the pressure of 0.3Torr. A pulse modulated rf(13.56MHz) discharge was generated between rf and grounded electrodes (6cm in diameter) at a separation of 2cm with keeping the rf voltage 200V (peak to peak). The rf voltage was periodically applied for 1.2ms and turned off for 450μsec in He plasma and for 180μsec in He+SF_6 plasma. Here, the off period of the He+SF_6 plasma was shorter than that of the He plasma because the off period same as the He plasma one was difficult to sustain the He+SF_6 discharge. The rf voltage was directly measured using an attenuator with a high input impedance and wide frequency response. Since the chamber also served inherently as a grounded electrode, asymmetrical discharges with a dc self-bias voltage on the electrode were realized. Negative and positive charge currents were measured by using a Langmuir probe biased at various potentials. The probe was placed at z= 1cm from the rf electrode in Fig.1.

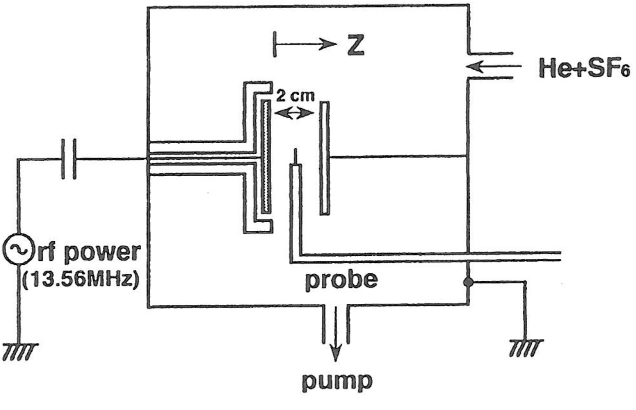

Fig.1 Experimental apparatus

3. Experimental Results and Discussion

Figures 2(a),2(b) and 2(c) show a typical result on time variations of the voltage V_{rf} applied on the rf electrode, the positive charge current I_+ and the negative charge current I_- collected by the probe at various fractions of SF_6 α in the He+SF_6 gases, respectively. The rf voltage is turned off at t= 0sec. Here, I_+ and I_- were the current collected by the probe biased at +25V and −40V, respectively. It is seen that I_+ decreases rapidly at t<40μsec and then decays slowly, while the magnitude of I_- increases at t<40μsec and then decreases monotonically. Figure 3 shows a time variation of the plasma potential V_s obtained from I–V curves of the probe in a He+SF_6(1%) at various times. The plasma potential also decreases rapidly at t <40μsec and then keeps the value roughly constant. The rapid decrease in the current I_+ and/or the increase in the current I_- would be due to this potential drop, although the physical reason of this drop is unclear at this stage. From Figs.2 and 3, the time at which the plasma potential saturates is roughly the same as that when the I_- becomes maximum and I_+ begins to decrease rapidly. In the region of t >40μsec the curves of I_+ and I_- might show the loss process of positive charges and negative charges, respectively.

Figure 4 shows a rising time τ_R and a decay time τ_D, respectively as a function of α or SF_6 fraction. Here, τ_D in a case of He+Ar plasma without negative ions are also shown for comparison between electronegative and elec-

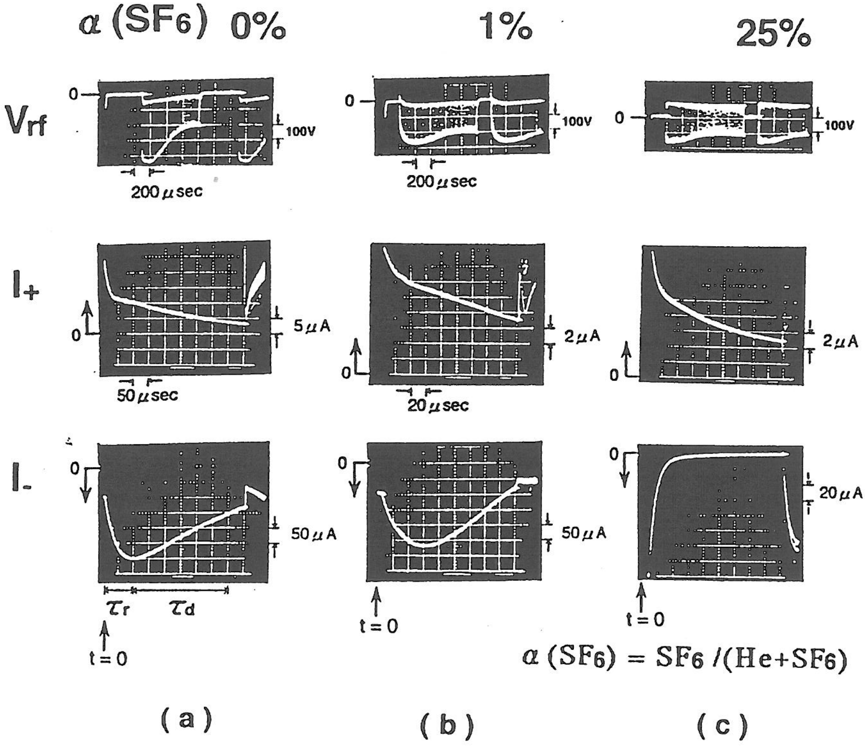

Fig.2 Typical time variations of the voltage V_{rf} applied on the rf electrode, the positive charge current I_+ and the negative charge current I_- for (a) the He plasma and (b) the He+SF_6(1%) plasma, (c) the He+SF_6(25%), respectively.

tropositive plasmas. τ_R and τ_D of the negative charge current I_- were defined as the time of the peak value and between the peak value and the half value of the peak one, respectively (see Fig.2). It is seen that τ_R of He+SF$_6$ plasma becomes short with increasing the SF$_6$ fraction, especially for α <5%, and then decays slowly. The time of τ_R is approximately equal to the time when the plasma potential saturates as above mentioned. It is also seen in Fig.4 that the profile of τ_D as a function of α in a He+SF$_6$ plasma producing negative ions decays quickly in the region of α <5% and then tends to reach the constant value (≈μsec) like the curve of τ_R, while τ_D in a He+Ar plasma without negative ions is roughly constant with the higher value (≈400−600μsec). Electrons are in general easy to diffuse towards the wall in the loss process in comparison to negative ions and the volume recombination rate of negative ions are higher than that of electrons. Thus, the latter result implies that the loss process of charged particles in the present system is dominated almost by a volume recombination rather than the diffusion to the grounded electrode and wall far from the plasma region (see Fig.1). The former result suggests that the addition of a few percent(<5%) SF$_6$ gas to He gas produces numerous negative ions in He+SF$_6$ plasma.

Figure 5 shows the time variation of the saturation current ratio of negative charge I_{S-} to positive charge I_{S+} collected by the probe in a He+SF$_6$(1%) after-glow plasma. The value of I_{S-}/I_{S+} increases until 40μsec, and then decreases. It tends to saturated at t >150 μsec. The increase in I_{S-}/I_{S+} at t

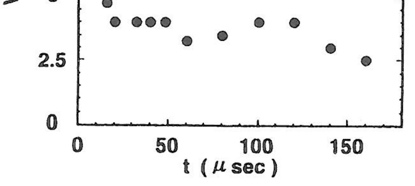

Figure 3

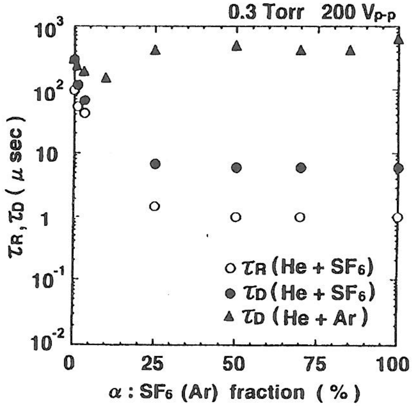

Figure 4

Fig.3 Time variation of plasma potential in a He+SF$_6$(1%) after-glow plasma.

Fig.4 Rising and decay time τ_R and τ_D,respectively as a function of SF$_6$ or Ar fraction (α).

<40μsec might be caused by the increase in electron current resulted from the drop of the plasma potential (see Fig.3). The decrease at t >40μsec suggests the increase in the ratio of negative ion density to the total negative charge density with decreasing the charged particle density. This would imply that the electron attachment to the SF_5 (or SF_4, F) molecules became active because of the decrease in the electron temperature in the after–glow plasma. Since the decay of negative ions should be more quick than that of electrons due to a big volume recombination probability, the practical ratio of negative ions to the total negative charges should become more higher than that in the apparent observation in Fig.5.

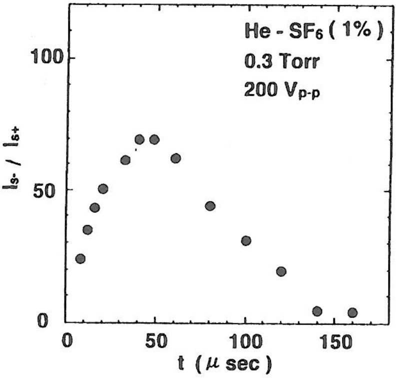

Fig.5 Time variation of the ratio of I_{S-}/I_{S+} in a He+SF_6(1%) after–glow plasma.

4. Conclusions

The loss process of negative charges in pulse modulated radio frequency discharges containing SF_6 in He gas has been studied experimentally with the probe. The results could be concluded as follows;

(1) The quick drop of the plasma potential was observed just after switching off the rf voltage.

(2) The increase in the only a little addition of SF_6 fraction provided a quick decay of charged particle density.

(3) The ratio of negative ion density to the total negative charge one continued to increase in the after–glow process.

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