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Oscillatory Phenomena in the Space Potential Hole made by the Pinpoint Plasma

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Negative space potential hole that a pinpoint plasma make produces oscillatory phenomena. This pinpoint plasma can be produced by a DC (direct current) glow-discharge. The two electrodes for the discharge used a large stainless disk for the cathode and a small stainless disk for the anode. A standing wave with a high frequency is excited by the behavior of ion beams produced by a strong electric field near the anode in this hole. The frequency and amplitude of the standing wave depend strongly on the discharge current and/or interval between the anode and cathode.

I. INTRODUCTION

There have been many experimental and theoretical studies of the behavior of ions in a plasma [1-6]. There have also been many several studies on the oscillatory phenomena of ions [7-10]. However, the results obtained were small amplitudes and low frequencies.

In this paper, a new mechanism of oscillation induced by a non-uniform field in a pinpoint plasma (used gas is an argon) is presented. The plasma was produced in a DC glow-discharge by using two electrodes, consisting of a large disk for cathode C and a very small disk for anode A. These electrodes form a non-uniform electric field. The electric field is greatly strengthened near the anode, and high-density plasma and ion beams are produced. Also, negative space potential hole is formed between the electrodes due to the formation of a double layer by ion beams injected in the plasma. The velocity of the ion beams is modulated by the space potential fluctuation (the frequency is the ion-plasma oscillation) in the sheath edge near the anode and reflected near the cathode. The standing wave is excited by the behavior of these ion beams. The excited wave is a sinusoidal wave with a high frequency and large amplitude. Also, the frequency of this standing wave is strongly dependent on the discharge current and/or the distance between the electrodes. By using this mechanism, a very simple and small oscillator that generates a large amplitude with high frequency (for example: V_{pp}=3.9 V, f=1060 kHz)) becomes possible.

II. EXPERIMENTS

The experiments were carried out in a cylindrical Pyrex chamber (diameter, 10 cm; length, 80 cm) as shown in Fig. 1. Here, the x-axis is the direction from cathode C to anode A, the z-axis is the direction of the cylindrical Pyrex chamber, and the center position of cathode C is x=0 and z=0. Cathode C is fixed at x=0 cm, and anode A can be moved in the x-axis direction. V_S is the direct-current power supply (V_S=0~600 V), R_o is the load resistance (R_o=60 Ω), and V_o is the output voltage. The standing wave signal is picked up using a small plane Langmuir probe (2×2 mm^2). The amplitude and frequency of the standing wave are measured using an oscilloscope (input resistance R_{in}=1MΩ) by directly connecting the probe with the oscilloscope. Ion energy distributions are measured by using a Faraday cup. Also, output signals can be obtain from the external load resistor R_0 connected to the discharge circuit (see Fig. 1). Plasma parameters were analyzed by using an X-Y recorder.

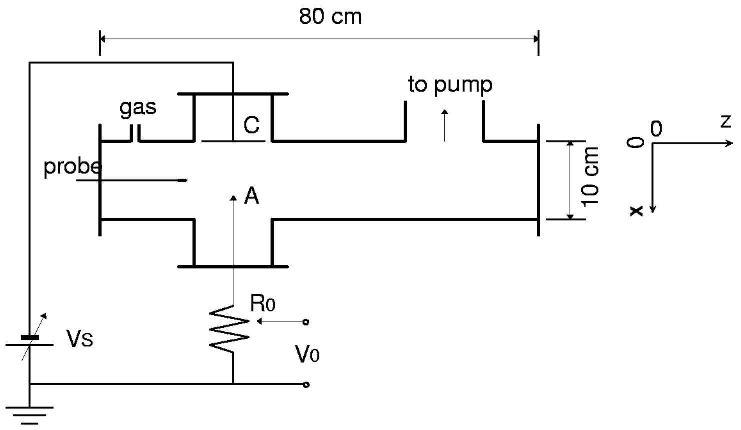

Fig. 1 Schematic of the experimental apparatus.
V_s: power supply. R_o: load resistor. V_o: output voltage.
A: anode. C: cathode.

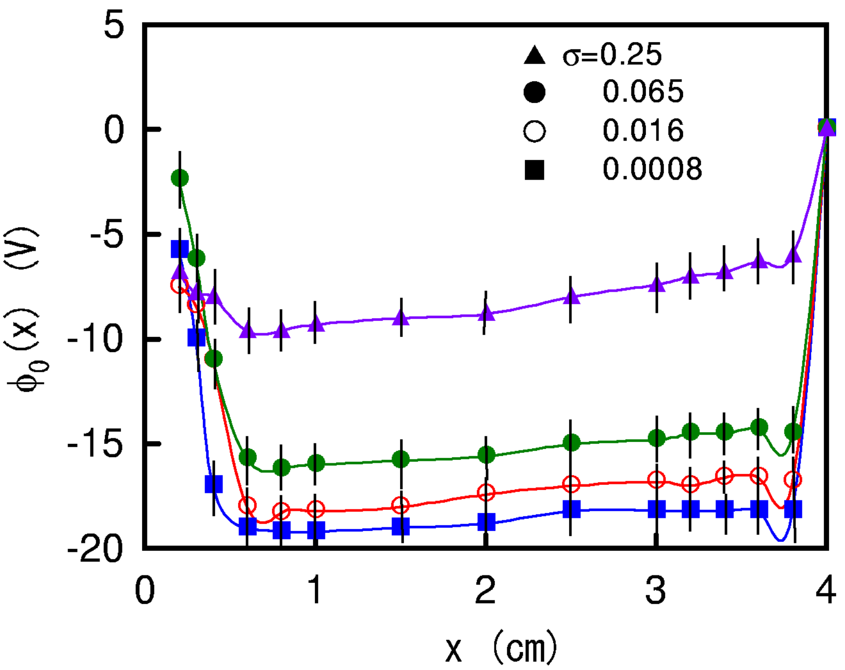

Fig. 2 Static space potential $\phi_0(x)$ as a function of distance x on each σ (=S_A/S_C; S_A : anode surface area, S_C: cathode surface area). AC=4 cm. I_d=15 mA. P=0.19 Torr.

When the surface area ratio $\sigma = S_A/S_C$ (S_A: anode surface area, S_C: cathode surface area) is smaller, the static space potential $\phi_0(L_{SE})$ becomes a deeper negative potential, as shown in Fig.2. Here, the distance between the cathode and anode is fixed to AC=4 cm, the discharge current is constant at I_d=15 mA, and the pressure is P=0.19 Torr. Also, the size of the anode surface area greatly affects the plasma production near the anode. That is to say, as the density of the electric line of force increases due to decrease in the anode surface area, the electron density increases. Consequently, frequency of the standing wave increases with decrease in the surface area ratio $\sigma = S_A/S_C$.

A typical standing wave that can be obtained from the probe is shown in Fig. 3. The oscillating waveform is a sinusoidal wave with frequency f=1200 kHz and amplitude $\tilde{V}/\overline{V}$=3.5 %. The measuring point of this standing wave is x=3.2 cm and z=0 cm. By directly connecting the probe signals to the oscilloscope (input resistance R_{in}=1MΩ), the wave potential can be measured. Here, the distance between anode A and the cathode C is AC=4 cm.

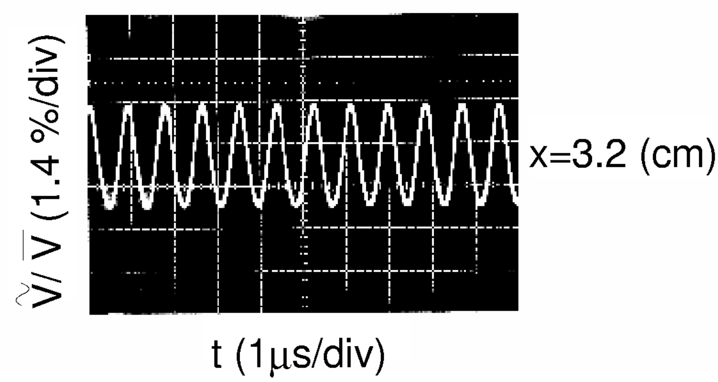

Fig. 3 Typical oscillatory wave form . Position of the probe is x=3.2 cm and z=0 cm; discharge voltage: V_d=510 V, discharge current: I_d= 16.2 mA, pressure: P=0.162 Torr, $\sigma=S_A/S_C$=0.0008; surface area of anode: S_A=0.04 cm^2, surface area of cathode: S_C=50.24 cm^2 , AC= 4 cm.

Ⅲ. DISCUSSION

1. Mechanism of Negative Space Potential

The applied potential on the anode is V_A=0 (V) and that on the cathode is V_C= –600 (V). As seen in the figure, a deeper potential hole is formed between the anode and the cathode. It is thought that a negative potential hole is formed due to double layer. This double layer is formed by space charges that are distributed in order to prevent ion-beams from being injected in the plasma [11, 12]. In this case, the velocity of ion beams v_{ib} that flow in the double layer from the high potential region is larger than the ion acoustic wave velocity C_s (v_{ib}=5.5-9.4×10^5 cm/sec and C_s≅1.5×10^5 cm/sec), and velocity of electrons v_e that flow in the double layer from the low potential region is larger than the electron thermal velocity v_{eth} (v_e =1.5-2.5×10^8 cm/sec and v_{eth}≅4.2×10^7 cm/sec).

2. Identification of an Oscillatory wave.

The relationship between frequency f obtained experimentally and electron density n_e is shown in Fig. 4. The closed circles show the experimental results of wave frequency, and the closed squares show the results of ion plasma frequency in argon plasma calculated by using Eq. (1):

$$\omega_{pi} = \left(\frac{4\pi n_e e^2}{m}\right)^{1/2}\left(\frac{m}{M}\right)^{1/2} = 33.2\sqrt{n_e}\ , \qquad (1)$$

where M is the ion mass of argon plasma. The experimental values almost agree with the theoretical values, as seen in Fig 4, so these waves seem to be standing waves of a ion acoustic type.

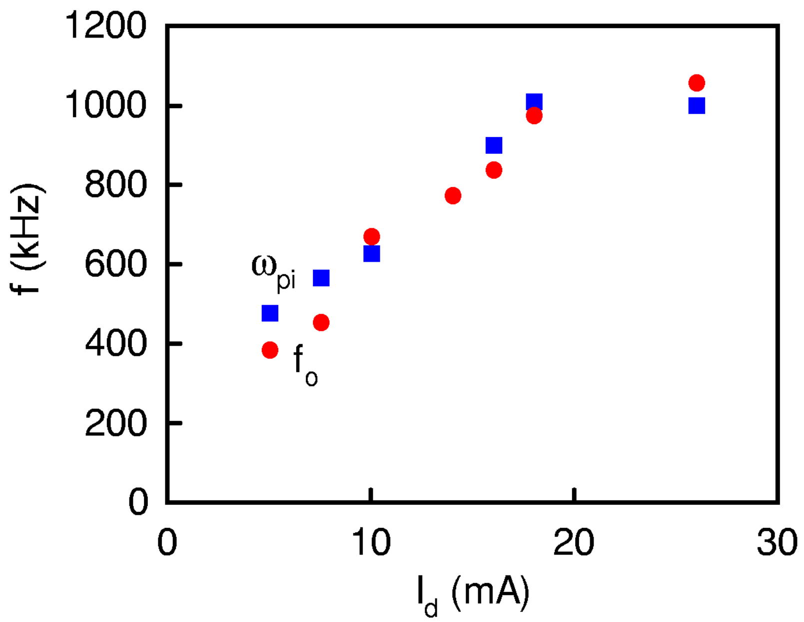

Fig. 4 Relationship between frequency f and on density n_e.
Pressure P=0.18 Torr, AC=6 cm, σ=0.0008.
■: ω_{pi}, ●: f_o .

IV. CONCLUSION

A deep negative space potential hole can be made by a DC glow-discharge using the anode of a small surface area and the cathode of a large disk. The standing wave is excited by behavior of the ion beams that run in the negative space potential hole. The ion beams are produced in the pinpoint plasma. This wave oscillation frequency depends strongly on the electron density of the pinpoint plasma

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