AXIAL ELECTRIC FIELD IN A NOBLE GAS NARROW TUBE DISCHARGE POSITIVE COLUMN PLASMA

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ABSTRACT

Narrow tubes or capillary tubes are used in plasma display system. In this work, the axial electric field in a noble gas narrow tube plasma has been studied both experimentally and theoretically for the pressure range from 0.01 to 10 torr. The tube inner diameter of 0.25, 0.4, and 1.5 mm narrow tube were used in the present investigation, together with axially movable anodes and 0.05 mm radius single electrostatic cylindrical probes for the electric field and the electron temperature measurements, respectively, in noble gases, i.e. He, Ne, Ar, Kr, and Xe. The light emissions are also taken during the experiment. Theoretical investigation was conducted by using electron energy conservation, charged particle and metastable transport equations.

1. INTRODUCTION

The noble gas mixture narrow tube or capillary tube discharge positive column plasma is often used in a plasma display system [4,9] and gaseous lasers. In this work, the axial electric field in a medium pressure (0.1 < p < 10 torr) noble gas narrow tube discharge positive column plasma has been studied both experimentally and theoretically. Studies of narrow or capillary tube positive column plasma has been conducted by numerous authors [1 - 3]. However, the influence of different kinds of noble gas has not been well investigated. These factors, especially for noble gases, have increased in importance as a result of recent development in optical applications of plasma.

2. EXPERIMENTAL APPARATUS

The tube diameter of 0.5, 0.8 and 3 [mm] DC discharge tube shown schematically in Figure 1 was used in the present investigation together with movable anode and 0.1 [mm] radius, 2 [mm] long cylindrical electrostatic cylindrical probes for axial electric field and electron temperature measurements, respectively. Optical emission from plasma was taken from axial directions. The axial electric field for 0.5 and 0.8 [mm] radius tubes was determined from the discharge voltages at fixed discharge currents in a different position along axial directions. In order to estimate possible anode fall region effects, measurements were conducted at several positions to confirm these effects as shown in Figure 2. Figure 2 shows that the effect of anode fall is not significant in the axial electric field determinations.

3. PLASMA CHEMISTRY

The charge transport and the electron conservation equations which contains, ionization elastic collisions, volume recombinations, ion-molecule reactions, thermal conductions and diffusions,
Figure 1  Schematics of experimental apparatus a) 0.25 and 0.4 [mm] radius tubes; b) 1.5 [mm] radius tube.

Figure 2  The effect of anode positions on the electric field measurements

Figure 3  Basic reaction chains for noble gases. $X^+$: atomic ions; $X_2^+$: molecule ions; e: electrons; $X^*$: metastables; X: neutra.
were needed to determine the plasma density profiles, axial electric field and electron temperatures for He, Ne, Xe, Kr, and Ar gases. The basic reactions involved in these gases are shown in Table 1 and Figure 3. All of the current experimental ranges, no molecule ions are observed from the theoretical predictions.

4. **PREDICTIONS OF THE AXIAL ELECTRIC FIELD**

From the collision dominated Boltzmann’s equation [5,6], the electron energy conservation can be rewritten as follows:

\[
\frac{5}{2} k (N_e \overline{v}_e \cdot \nabla T_e + T_e G_e) - \nabla \cdot (k \nabla T_e) + e N_e \overline{v}_e \cdot E = \varepsilon_e
\]  

(1)

where \( J \) is the current flux, \( \overline{V}_e \) is the average velocity, \( N \) is the number density, \( T \) is the temperature, \( K \) is the thermal conductivity \((5 N_e k^2 T_e/2 m_e \sim \varepsilon_{m})\), \( k \) is Boltzmann’s constant, \( m \) is the mass, \( \varepsilon \) is the net energy gain per unit time and volume, \( G \) is the charged particle generation per unit time and volume, \( e \) is the elementary charge, \( \langle \varepsilon_{m} \rangle \) is the momentum transfer collision frequency, and subscript \( e \) refers electron.

Here, the electron transport equation is

\[
J_e = N_e \overline{v}_e = - D_e \nabla N_e + \mu_e N_e \overline{E}
\]  

(2)

With uniform axial electric field electron density and electron temperature assumptions in the positive column, we obtain

\[
\frac{5}{2} k T_e G_e - e \mu_e N_e = \varepsilon_e
\]

(3)

\[
= - (G_{\text{inelastic}} + G_{\text{elastic}}) \frac{3}{2} N_e \langle \varepsilon_{m} \rangle > k (T_e - T_g)
\]

for the atomic gas, where \( G_{\text{inelastic}} \) and \( G_{\text{elastic}} (= 2 m_e / m_g) \) are the collision factor due to inelastic and elastic collisions, respectively. We considered ion chemistry for each gas as shown in the Figure 3 to evaluate \( G_e \) terms. We obtain axial electric field as follows:

\[
E_z = \left( \frac{5 k T_e G_e}{2 e \mu_e} + \left( G_{\text{inelastic}} + \frac{2 m_e}{m_g} \left[ \frac{3 \varepsilon_{m} k (T_e - T_g)}{2 e \mu_e} \right] \right)^{1/2} \right.
\]

(4)

Axial electric field obtain from the equation (4) with \( G_{\text{inelastic}} = 0 \) is shown as a function of electron temperature in Figure 4 for noble gases, where \( \mu_e \) and \( \langle \varepsilon \rangle \) from the theoretical results of Baille et al [7]. The results show that the axial electric field significantly decreases with increasing gas pressures and increases with increasing electron temperature. However, the axial electric field has a nonmonotonic dependence on the mass or ionization potentials of the noble gas.

<table>
<thead>
<tr>
<th>Table 1 Plasma Chemistry in Noble Gases</th>
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<td>X⁺ + 2X → X₂⁺ + X</td>
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<tr>
<td>X₂⁺ + e → X⁺ + X</td>
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<td>X⁺ + e → X + hv</td>
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Figure 4  Calculated axial electric field as a function of electron temperature for noble gases.

Figure 5  Axial electric field as a function of pR (gas pressure x tube radius) for I_D = 30 [mA], and R = 0.4 [mm].

Figure 6  Axial electric field as a function of pR for I_D = 20 [mA] and R = 0.4 [mm].

Figure 7  Axial electric field as a function of pR for I_D = 20 [mA] and R = 0.25 [mm].
Figure 8  The relative intensity of the emission spectrums; electron temperatures and axial electric fields as a function of pR for R = 1.5 [mm] and I_D = 20 [mA]. — experiment; --- theory.

a) Helium;  b) Neon.
5. EXPERIMENTAL RESULTS AND DISCUSSIONS

The axial electric field, \( E_x/p \), as a function of gas pressure, \( pR \), for various noble gases at the discharge current \( I_D = 30 \text{ [mA]} \), for tube radius \( R = 0.4 \text{ [mm]} \) is shown in Figure 5. Figure 5 shows that the axial electric field decreases with increasing gas pressures and noble gas masses. The noble gas mass dependence on the axial electric field in terms of \( pR \) was assessed, since the electron temperature increases with decreasing \( pR \) [2, 5, 10, 11].

Similar results for different discharge currents and different tube radius is shown in Figures 6 and 7, respectively. No significant extra tube radius effect on the axial electric field was observed, if we analyzed results in terms of \( pR \) as shown in Figures 6 and 7. Figures 5 and 6 show that the axial electric field decreases only slightly with increasing discharge current. The relative intensity of the emission spectrums, electron temperatures and axial electric fields as a function of \( pR \) for \( R = 1.5 \text{ [mm]} \) tube at \( I_D = 20 \text{ [mA]} \) are shown in Figure 8(a) and (b) for Helium and Neon, respectively. The results show that the emission spectrums have a maximum near \( pR = 1 \text{ [Torr cm]} \), where the axial electric field observed to be sharper decreasing trends while the electron temperature becomes saturations. The location of maximum approximately equals to the electron Knudsen number near unity.

6. CONCLUDING REMARKS

Axial electric fields in a noble gas narrow tube discharge positive column plasma has been studied both experimentally and theoretically. The results show that: (1) the axial electric field/pressure, \( E_x/p \), decreases with decreasing (pressure x tube radius), \( pR \), and atomic weight of gas; (2) \( E_x/p \) decreases slightly with increasing gas discharge currents; (3) theoretically predicted \( E_x/p \) agree well with present experimental results; (4) No significant extra tube radius effect on \( E_x/p \) was observed from both experimental and theoretical results, if we analyzed results in terms of \( pR \); (5) relationships between axial electric field and optical emissions from plasma observed to be exist, however, the cause of correlations are still need to be study.

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REFERENCES