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PRODUCTION OF MULTIPLY CHARGED IONS FROM RF ION SOURCE

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A design of the RF ion source is made to develop its capability for production of multiply charged ions by the use of magnetic mirror, mechanical constriction at the plasma tube center and electron beam-plasma interaction. An emphasis is given to study the plasma characteristics i. e. density, electron temperature, plasma oscillations, by the use of cylindrical Langmuir probe. It was found that the magnetic field increases the discharge intensity from 10^9 electrons/cm^3 at $B = 0$ to $\approx 10^{12}$ electrons/cm^3 at $B = 0.028$ T. The mechanical constriction increases the plasma density to $\cong 4.3$ times the value of the plasma density without mechanical constriction. With electron plasma interaction the intensity of the plasma increases to reach more than 10^{12} electrons/cm^3. Also the amplitude and frequency of the plasma oscillations increase with the increase of the extraction potential. Both the increase of the plasma intensity and plasma oscillations make the value of Ar^{+3}, Ar^{+4} larger than the value without electron plasma interaction.

1. Introduction

1.1 *Magnetic mirror*

The longitudinal magnetic field is often useful to increase the effective path of electrons and the rate of ion production in the ion source, because the electrons follow spiral trajectories, owing to the crossed electromagnetic fields. The longitudinal magnetic field is also effective in concentrating the plasma along the axis.

If the extraction hole is slightly beyond the magnetic mirror most of the energetic electrons are reflected before reaching the hole (due to the concentration of their magnetic moment ($W_{\perp}/B$)) and this fact facilitates the ion electron separation near the extraction gap. This is also necessary for the production of high intensity stripped ion beam at steady state.

1.2 *Electron plasma interaction*

This causes high frequency oscillations; a high degree of electron stripping of ions occurs in the beam plasma type ion source which has high efficiency of ionization, and so multiply charged ions will be obtained effectively.

Several authors[1,2] investigated the generation of microwave noise when a magnetically focused electron beam passes through a residual gas. They have shown that this noise generation results from the creation of a dense plasma. The impressive significance of these results is that it is possible to strip electrons from heavy ions efficiently in the presence of energetic electrons.

1.3 *Mechanical constriction in the plasma tube*

The radial density distribution is maximum ($=n_0$) at the plasma axis and follows a Bessel function of the zero order[3]

$$n_r = n_0 J_0 (2.405\, r/R) \tag{1}$$

where R is the tube radius.

From the theory of the electron distribution in the low pressure RF plasma[4], the radial density (n_0) at the plasma axis is found to be:

$$n_0 = I_p / 1.36\, e\, v\, R^2 \tag{2}$$

where I_p is the discharge current and v is the velocity of the particle in the RF field. Eq. (2) shows the dependence of (n_0) on the inverse square of the tube radius. A design was made of an ion source based on this result by having a reduced radius at the central region of the plasma tube[5], producing plasma confinement in a manner simillar to what happens in the baffle canal of the intermediate anode of the duoplasmatron source (Fig. 2). This leads to an increase of the intensity at the source center.

2. *The source*

The source is of the radial extraction type with central constriction[6] (Fig. 1). The longitudinal magnetic field has a mirror shape at the middle of the source with extraction aperture beyond the magnetic mirror. Simple electron gun (hot filament and accelerating electrode) is used to inject electrons into the plasma tube from a hole at the top of the magnetic mirror.

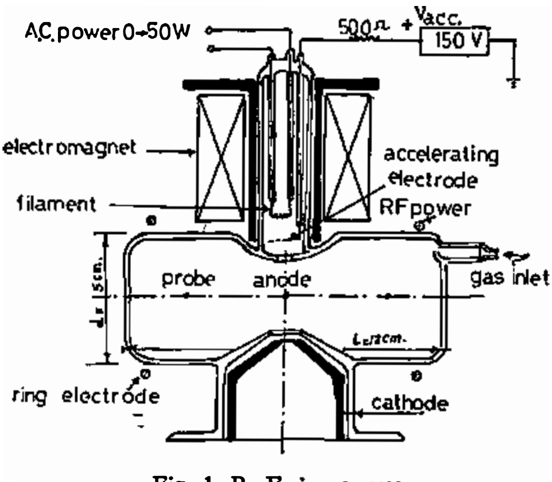

Fig. 1. R. F. ion source.

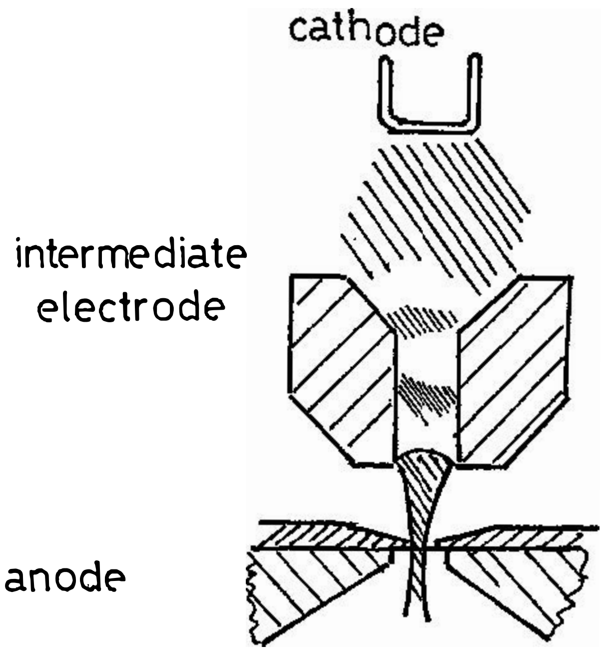

Fig. 2. Schematic diagram of the duoplasmatron ion source.

3. *Determination of the plasma intensity at the source center*

a) A Langmuir cylindrical probe is used to measure the plasma intensity at 1 cm from the tube wall (n_{r1}).

b) The relation between the plasma density at the axis n_{01} and the density n_{r1} at r_1 (the probe positions) is obtained from Eq. (1) (where r_1, R are 1.5 cm, 2.5 cm, respectively) as follows

$$n_{r1} = n_{01} J_0 \cdot 1.443 = 0.5436\, n_{01}. \tag{3}$$

c) The plasma density at the source center (n_{02}) (assuming n_{01} is constant along the plasma tube axis) could be calculated from $n_{02}/n_{01} = R_1^2/R_2^2$ where R_1 is the radius of the constriction and $R_2 = R$ is the tube radius

$$n_{01} \left(\frac{2.5}{1.2}\right)^2 = n_{01} \cdot 4.34 \tag{4}$$

i. e., the mechanical constriction increases the plasma intensity to about 4.34 than that value without constriction. From Eq. (3)

$$n_{02} = \frac{n_{r1}}{0.5436} \cdot (4.34) = 8 n_{r1}. \tag{5}$$

4. *Results and discussions*

The probe characteristics (ln (I) vs. V) are shown in Fig. 3 for RF plasma without electron plasma interaction and in Fig. 4 for RF plasma with electron plasma interaction, which are measured at 1 cm from the tube wall with single Langmuir probe. From the kinetic theory[7] the random electron current density is

$$J_e = \frac{1}{4} N_e e \overline{V} = N_e e \, (kT_e/2\pi m_e)^{1/2} \tag{6}$$

and

$$T_e = \frac{e}{k} \left[\frac{\partial}{\partial V} (\ln (J_p + |J_i|)\right]^{-1} \tag{7}$$

where J_e is the current density of electrons, $\overline{V}$ its mean velocity, e electron charge, k Boltzmann's constant, m_e mass of the electron and T_e the electron temperature. The generated plasma density has been calculated from the ion and electron current saturation I_{sat} using the relation

$$I_{sat} = 0.45\, n_e e A \, (2kT_e/m_e)^{1/2} \tag{8}$$

where $(kT_e/m_e)^{1/2}$ is the electron velocity at the plasma edge.

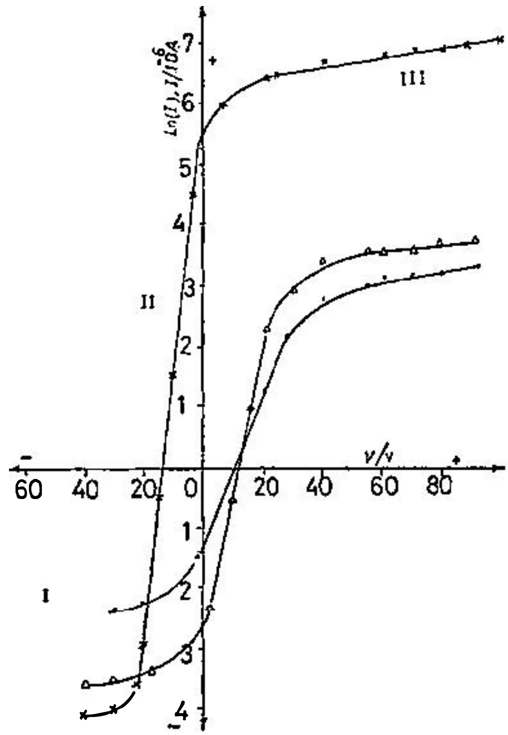

Fig.3

Fig. 3. Electric probe characteristics without electron injection. (V_{ex} = 0.0 V, P_r = 0.133 Pa, $P_{r.f.}$ = 145 W, P_{fu} = 0.0 W, B = 0, B = 0.014 T, B = 0.028 T, I = probe current and V = probe voltage.)

In Eq. (7) the term between brackets is the inverse slope of natural logarithmic probe current to the probe voltage in the region II. The saturation ion and electron current is represented by region III and I and the deviation from the saturation value is mainly due to secondary ionization processes. The plasma density related to these characteristics at the source center (from Eq. (5)) without use of the magnetic field $\cong 1.26 \times 10^9$ electrons/cm^3. With the use of the magnetic field the plasma density increases logarithmically (Fig. 5) to reach $\cong 1.13 \times 10^{12}$ electrons/cm^3 at $B = 0.028$ T.

With electron plasma interaction the plasma density varies from $n_e = 1.2 \times \times 10^{12}$ electrons/cm^3 at $B = 0$ to $\cong 1.99 \times 10^{12}$ electrons/cm^3 at $B = 0.028$ T. It is clear that the magnetic field effect is to increase the plasma density and this effect is like the increase of the discharge pressure.

The electron temperature variation with the applied external magnetic field is shown in Fig. 6. Without electron plasma interaction it shows two different regimes. At low values of the magnetic field the electron temperature decreases with the increase of the magnetic field intensity up to $B = 0.014$ T. The second region appears for $B > 0.014$ T which shows the electron temperature begins to

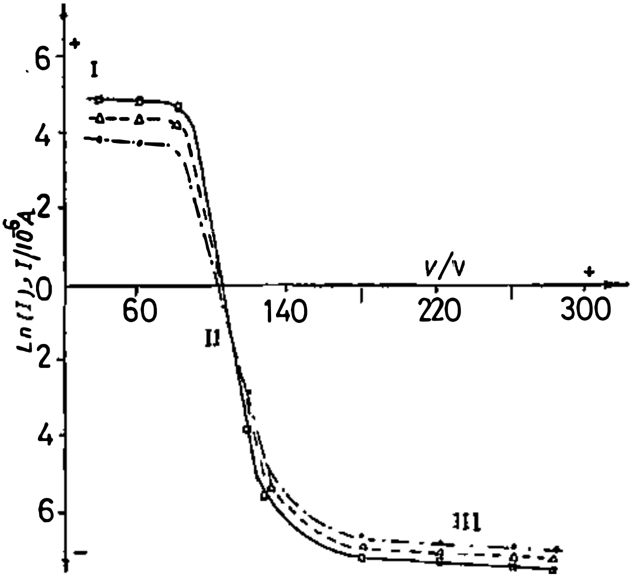

Fig. 4. Electric probe characteristics with electron injection. (P_r = 0.133 Pa, P_{fil} = 10 W, V_{ex} = = 0, $P_{r.f.}$ = 145 W, B = 0, B = 0.014 T, B = 0.028 T, I = probe current and V = probe voltage.)

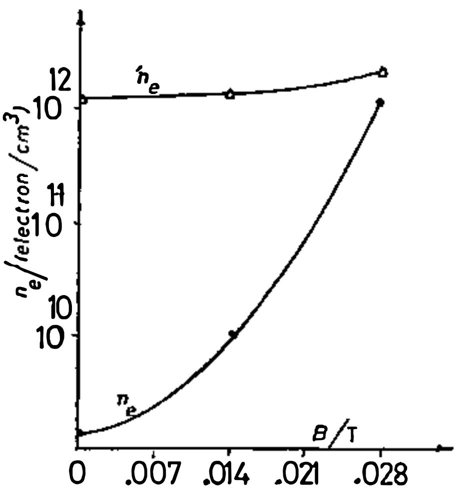

Fig. 5. Variation of electron density of the plasma with magnetic field (n_o = electron density/cm^3 at P_{fil} = 0.0 W, n_e = electron density/cm^3 at P_{fil} = 10 W.)

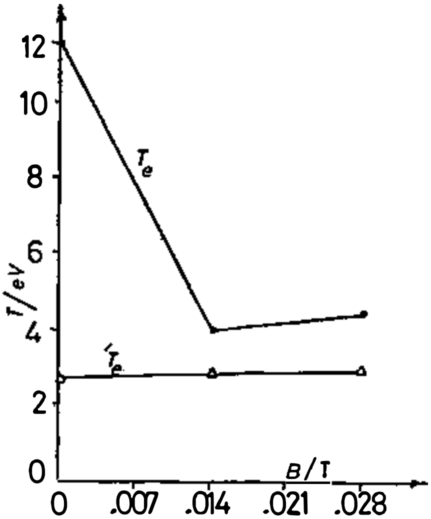

Fig. 6. Variation of electron temperature of the plasma with magnetic field. (T_e = electron temperature at $P_{fit} = 0$, T_e = electron temperature at P_{fit} = 10 W.)

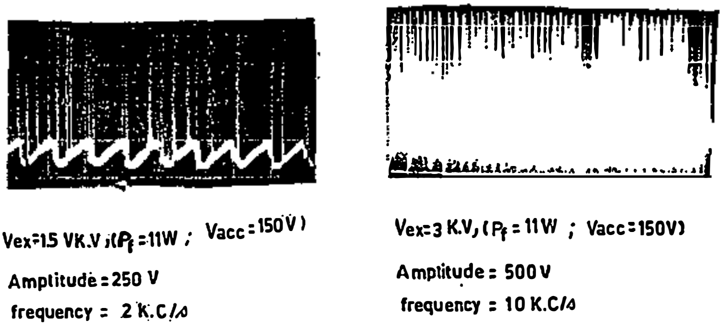

Fig. 7. Two photos of the plasma oscillations.

increase with a slow rate. At $B = 0.014$ T an electron cyclotron resonance occurs inside the discharge which has minimum breakdown voltage. The electron-plasma interaction decreases the electron temperature of the plasma due to increasing the intensity of the discharge and the successive reduction of the mean free path leading to a lowering of energy acquired by electron between collisions.

Fig. 7 shows two photos of the plasma oscillations for RF plasma with electron plasma interaction. Both amplitude and frequency of the plasma oscillations increase with the increase of the extraction voltage, which varies from $V_{peak} = 250$ V, $f = 2$ kHz at $V_{ex} = 2$ kV, to $V_{peak} = 500$ V, $f = 10$ kHz at $V_{ex} = 3$ kV.

Mass spectrum of argon ion beams is shown in Fig. 8 which shows increase of the value of Ar^{+3}, Ar^{+4} with electron-plasma interaction. This results from the increase of the plasma intensity and plasma oscillation with electron-plasma interaction.

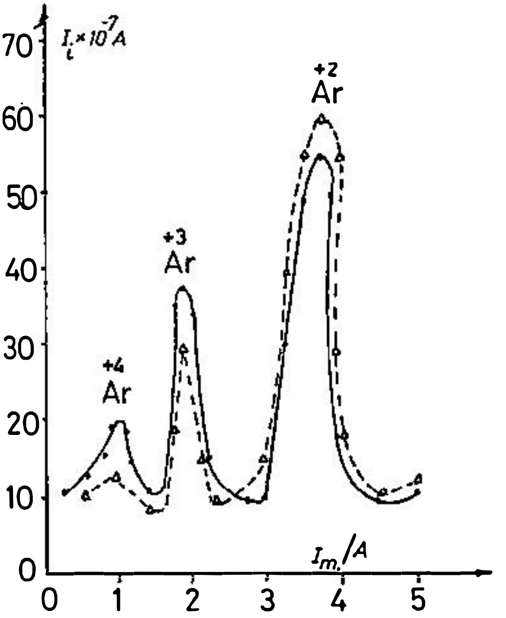

Fig. 8. Mass spectrum of argon ions. ($P_{fu} = 0$ - - -, $P_{fu} = 10$ W ——, I = analized ion current ($I \cdot 10^{-7}$ A), I_m = the coil current of the magnetic analyzer.)

5. Conclusion

The design of the RF ion source with radial extraction, central constriction, magnetic mirror and electron-plasma interaction increases the plasma intensity, as well as to raise the frequency and amplitude of plasma oscillations at higher extraction potential, thereby increasing the sources capability for production of multiply charged ions.

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STVARANJE VIŠESTRUKO NAELEKTRIZIRANIH IONA POMOĆU RF IONSKOG IZVORA

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Razmatrano je stvaranje višestruko naelektriziranih iona pomoću RF ionskog izvora. Date su karakteristike aparature konstruirane za efikasnije dobijanje višestruko ioniziranih čestica. Ionizacija se vrši u prisustvu plazmenih oscilacija izazvanih elektronskim snopom prilikom njegovog prolaska kroz argonsku plazmu koja se ispituje. Rezultati mjerenja ukazuju na prednosti razmatranog uređaja u smislu povećane produkcije višestrukih iona.