PLASMA DENSITY MEASUREMENT OF RF ION SOURCE

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For a radiofrequency (27.12 MHz) inductively coupled ion source (3 cm diameter, 7 cm long, without external magnetic field, working gas-hydrogen, helium, argon), measurements of the average plasma density were made using an 8 mm microwave interferometer. The range of neutral gas pressure is 2-30 mTorr and RF-power is in the range 20-400 W. It is found that the plasma density increases with increased gas pressure and RF-power. A global discharge model is applied to relate the electron densities and the electron temperature in an argon plasma to the pressure and input power ranges of interest. The model calculations are compared to measured plasma density, showing fair agreement.

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1. INTRODUCTION

Radiofrequency inductively coupled ion sources are widely used for the nuclear microprobe applications. High beam brightness of these ion sources can be achieved by extracting the beam with high current density which is proportional to plasma density and square root of the electron temperature [1]. To measure the average plasma density in different operational ion source conditions, 8 millimeter wave interferometry technique is applied as unperturbing method for plasma diagnostics.

For analyzing RF discharge and quick prediction of the plasma parameters, a global model [2] of an argon discharge was employed. In a global model the space-average particle and energy balance equations are solved simultaneously. The average values of the plasma density and of the electron temperature are obtained.

In this paper we present the results of the plasma density measurements, using 8 mm wave interferometer. The values of the electron density of argon plasma obtained from interferometer measurements are compared with global model calculations.

2. 8 MM MICROWAVE INTERFEROMETER

To measure average plasma density of a RF ion source, 8 mm (37.5 GHz) microwave interferometer has been developed. The interferometer works on the Mach-Zehnder principle in which the plasma is in one arm of the two-beam interferometer. In low pressure discharge where the wave frequency is much greater than the plasma and collision frequency, only phase change between two arms are needed for a density measurements and a linear relationship exists between the average plasma density and the phase difference.

A homodyne conversion of the frequency is realized due to sawtooth frequency modulation of a microwave generator and use an unequal-path bridge hybrid. To form a reference signal of an intermediate frequency, the patented device on the basis of a cavity resonator is applied. The intermediate frequency is 20 kHz. In comparison with the traditionally used for this purpose a reference unequal-path bridge hybrid [3], the interferometer scheme becomes simpler and more compact with the high stability of an initial difference of phases. The minimum measured phase shift makes 1.5 degree, that corresponds to the plasma density of $3\cdot10^{10}$ cm^{-3}. The maximum definitely measured phase shift 360° corresponds to the plasma density of $9\cdot10^{12}$ cm^{-3}.

3. EXPERIMENTAL SETUP

The schematic of the experimental setup is shown in Fig.1. and was reported elsewhere [4]. The ion source (without external magnetic field) consists of the discharge quartz tube (3 cm in diam and 7 cm long), surrounded by a helical copper antenna (4 coils). A 27.12 MHz, 40 W oscillator and 800 W RF power amplifier (Acom 1000) are connected to the antenna through matching box.

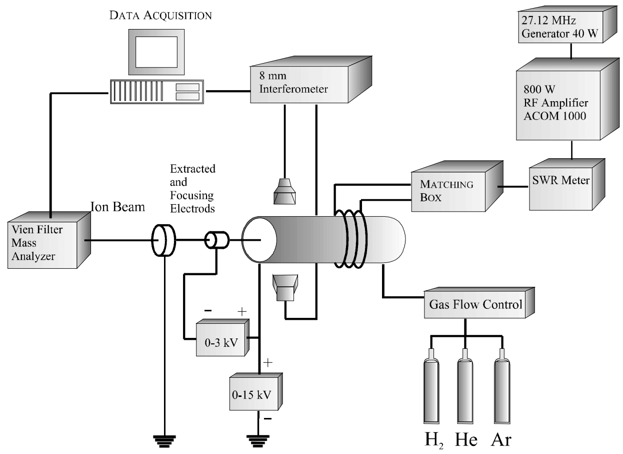


Fig.1. Schematic of the experimental setup

The forward and reflected RF power is controlled by SWR meter. Input RF power is varied up to 400 W. The ion source is connected to two beam diagnostic chambers and whole system is evacuated by a turbo-pump and mechanical pump to a basic pressure of about 10^{-6} Torr. Hydrogen, helium and argon gases were utilized for plasma generation, and the operational pressure range was from 2 to 30 mTorr.

4. GLOBAL MODEL [2]

The characteristics of the argon plasma are determined by the particle and power balance within the discharge. The global discharge model assumes all densities to be volume averaged. The electron temperature can be determined by equating the total volume ionization to the surface particle loss to obtain

$$\frac{K_{iz}(T_e)}{u_B(T_e)}=\frac{1}{n_g d_{eff}} ,$$

where

$$d_{eff}=\frac{1}{2}\frac{RL}{Rh_L+Lh_R} \quad (1)$$

is an effective plasma size, h_L and h_R are geometrical factors relating the plasma density at the sheath edge to that in the bulk

$$h_L=0.86\left(3.0+\frac{L}{2\lambda_i}\right)^{-1/2},$$

$$h_R=0.8\left(4.0+\frac{R}{\lambda_i}\right)^{-1/2} \quad (2)$$

The ion mean free path is taken to be $\lambda_i=\frac{1}{n_g\sigma_i}$, where $\sigma_i\approx10^{-18}$ m^2 is the ion-atom scattering cross-section for low energy argon ions. The neutral gas density $n_g=3.25\cdot10^{19}\cdot p$ (m^{-3}), where p is gas pressure (mTorr). Solving equation (1) using the ionization rate constant for argon gives an estimate of the electron temperature for different values of gas pressure.

All supplied power is assumed to be absorbed by the plasma and its loss is modeled as follows: part of the power is used in creating electron-ion pairs and this loss represents both elastic and inelastic electron collision processes, while the remaining part is lost as kinetic energy of both ions and electrons as they leave the plasma. For a single electron-ion pair lost at the wall the total energy loss E_T is defined by

$$E_T=E_{ew}+E_{iw}+E_c \quad (3)$$

where the electron kinetic energy E_{ew} and ion kinetic energy E_{iw} at the wall are defined by

$$E_{ew}=2\mathrm{T}_e \text{ and } E_{iw}=V_s+T_e/2 \quad (4)$$

Here T_e is the electron temperature expressed in units of volts, and V_s is the sheath voltage. For argon $V_s\approx4.7\mathrm{T}_e$, thus ions have average kinetic energy at the wall $E_{iw}\approx5.2\mathrm{T}_e$. E_c is the collision energy loss per electron-ion pair created [2]

$$E_c=E_{iz}+\sum_i E_{ex,i}\frac{K_{ex,i}}{K_{iz}}+\frac{K_{el}}{K_{iz}}\frac{2\mathrm{m}_e}{M}\frac{3\mathrm{T}_e}{2} \quad (5)$$

where E_{iz}=15.76 V is the ionization energy for argon, $E_{ex,i}$ is the energy for the i-th excitation process, K_{iz} is the ionization rate constant, $K_{ex,i}$ is the rate constant for the i-th excited state and K_{el} is the elastic rate constant In the steady state, supplied and lost power must be balance and the plasma density is predicted

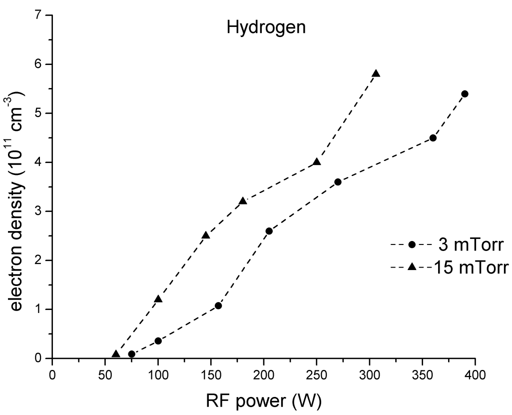
$$n_0=\frac{P_{abs}}{eu_B A_{eff} E_T} \quad (6)$$

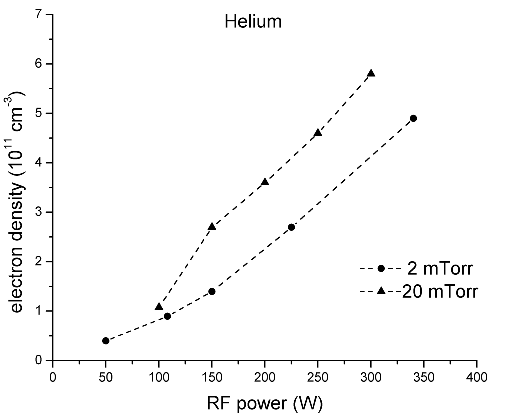
where P_{abs} is the power supplied, n_0 is the center (bulk) electron density, u_B is the Bohm velocity. For a cylindrical plasma chamber, with radius R and length L, the expression for the effective area is

$$A_{eff}=2\pi\mathrm{R}\left(Lh_R+Rh_L\right) \quad (7)$$

5. EXPERIMENTAL RESULTS

The plasma of RF ion source was initiated in the capacitive E-mode and subsequently it was transformed to the inductive H-mode by increasing the RF power. Hysteresis is seen. The E-H transition occurred approximately at 60 W power. The plasma density measurements were made for H-mode only. The position of antenna horns is about 1 cm from the RF antenna. Measurements of average electron density as a function of RF power are presented in figure 2 for hydrogen, helium and argon. Figure 3 shows the global model calculations of electron temperature T_e and argon ion current density j_i which can be extracted from the ion source.





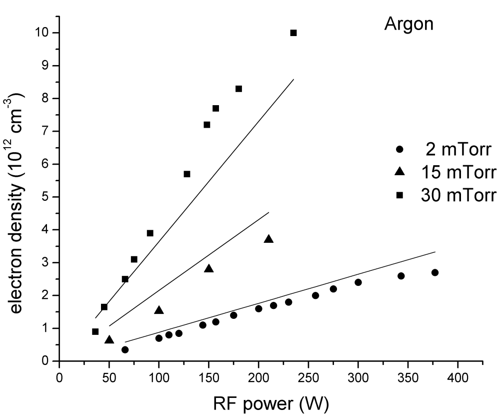


Fig.2. Experimental points and calculated global model curves (solid) for electron density n_0 versus RF power for H_2 ,He and Ar at different pressure

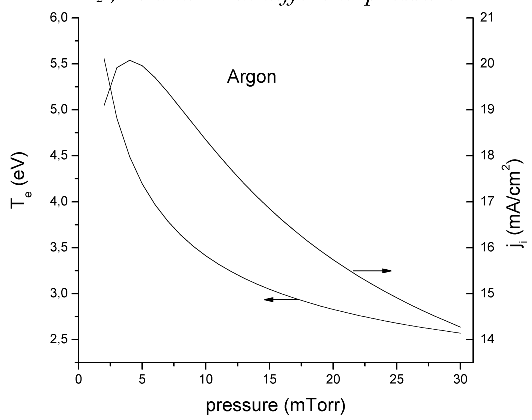


Fig.3. Calculated curve for electron temperature T_e and ion current density j_i (for 100 W RF power) versus argon pressure

CONCLUSION

A 8 mm microwave interferometer has been developed to measure average plasma density in hydrogen, helium and argon discharge of a inductively coupled RF ion source. The range of neutral gas pressure is 2-30 mTorr and RF power is in the range of 20-400 W. The interferometer measurements indicate that the plasma density increases monotonically with gas pressure and linearly with RF power and reaches the values of $5\cdot10^{11}$ cm^{-3} for H_2 , He and $5\cdot10^{12}$ cm^{-3} for Ar at 300 W RF power.

A global discharge model is applied to relate the electron densities and the electron temperature in an argon plasma. The electron temperature calculated using this model only depends on the neutral gas pressure and geometry of the discharge (Fig.3). The argon ion current density that could be extracted from this ion source is about 60 mA/cm^2 for 300 W RF power at the pressure of 5 mTorr and decreases with increase of the pressure.

The global model calculations are compared to measured plasma density and a reasonably good agreement is found.

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ИЗМЕРЕНИЕ ПЛОТНОСТИ ПЛАЗМЫ ВЧ-ИСТОЧНИКА ИОНОВ

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Для высокочастотного (27.12 МГц) индуктивного источника ионов (3 см в диаметре и длиной 7 см, без внешнего магнитного поля, рабочий газ - водород, гелий, аргон) были выполнены измерения средней плотности плазмы с помощью 8-ми миллиметрового интерферометра. Давление рабочего газа изменялось в диапазоне 2-30 мТорр, ВЧ-мощность - в диапазоне 20-400 Ватт. Установлено, что плотность плазмы растет с увеличением рабочего давления и входной ВЧ-мощности. Чтобы рассчитать электронную плотность и электронную температуру аргоновой плазмы в интересующем нас диапазоне давлений и ВЧ-мощности, была применена глобальная модель плазменного разряда. Вычисленная по глобальной модели плотность плазмы находится в хорошем согласии с экспериментально измеренной величиной.

ВИМІРЮВАННЯ ЩІЛЬНОСТІ ПЛАЗМИ ВЧ-ДЖЕРЕЛА ІОНІВ

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Для високочастотного (27.12 МГц) індуктивного джерела іонів (3 см у діаметрі і довжиною 7 см, без зовнішнього магнітного поля, робочий газ - водень, гелій, аргон) були виконані виміри середньої щільності плазми за допомогою 8-ми міліметрового інтерферометра. Тиск робочого газу змінювався в діапазоні 2-30

мТорр, ВЧ-потужність - в діапазоні 20-400 Вт. Встановлено, що щільність плазми росте зі збільшенням робочого тиску і вхідної ВЧ-потужності. Щоб розрахувати електронну щільність і електронну температуру аргонової плазми в цікавлячому нас діапазоні тисків і ВЧ-потужності, була застосована глобальна модель плазменного розряду. Обчислена по глобальній моделі щільність плазми знаходиться у гарний згоді з експериментально обмірюваною величиною.