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Plasma Parameter Characterization of a DC Multicusp Plasma Chamber Operating in He, Ar and Xe Gas

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Abstract

A large dc multicusp plasma chamber has been constructed and installed at Chiang Mai University. The first prototype has a 31.2 cm diameter and a 42.5 cm length and is surrounded by 632 ceramic permanent magnet buttons with a maximum magnetic field of about 2.2 kG for each. The magnetic field at the stainless steel wall with a thickness of 2 mm is about 670 G. A tungsten (W) filament was used as a source of primary electrons. The estimated discharge voltage for helium gas (He), argon gas (Ar), and xenon gas (Xe) was 40 V and the discharge operating current varies from 500 mA to 1 A. Plasmas can be confined within a 20 cm diameter region which are uniformly distributed along the axial path. The plasma density was measured by a single cylindrical Langmuir probe to be between 4.8×10^{8} – 4.9×10^{9} cm^{-3} with 650 watts of power applied to the tungsten filament and the gas pressure inside the chamber of 3.8×10^{-4} Torr. Results of the ion density measurements are described. The proportionality constants in the relation between the ion current density arriving at the plasma electrode and the maximum plasma density and the ion sound speed for helium, argon and xenon are found to be 0.42 ± 0.07, 0.59 ± 0.08, and 0.46 ± 0.06, respectively.

Keywords:

plasma chamber, multicusp field, dc discharge, ion density profile, helium, argon, xenon

1. Introduction

In recent years, multicusp plasma sources have been utilized as ion sources in ion and plasma based processes for materials modification. The plasma chamber is usually surrounded by a certain arrangement of permanent magnets which can produce a large volume of uniform and quiescent plasma with a density exceeding 10^{12} cm^{-3} [1, 2]. These magnetic multicusp devices were shown also to be good candidates for the production of intense uniform ion beams [3].

A large multicusp plasma test chamber, based on the pioneering work of Leung *et al.* [2-9] was constructed and installed at Chiang Mai University. The first prototype has a diameter of 31.2 cm and is 42.5 cm long as shown in the photograph in Fig. 1. It is primarily intended to be used as a source of atomic and molecular particles for the purpose of studying plasma parameter characterizations.

In this reference, the characteristics of a multicusp plasma generator operating with helium (He), argon (Ar), and xenon (Xe) gases are described. A hot tungsten (W) wire produces electrons, which are emitted and accelerated between the filament cathode and the

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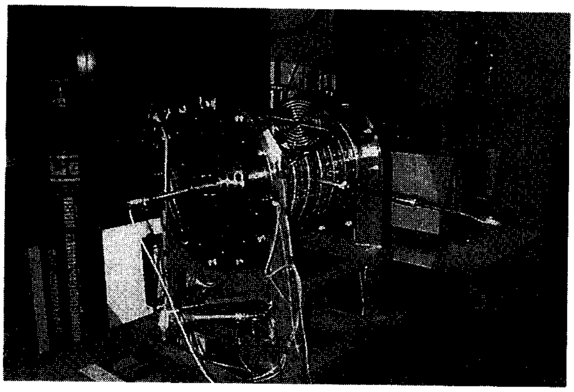

Fig. 1 A dc multicusp plasma source chamber at Chiang Mai University.

anode wall of the chamber. The neutral gas in the chamber is ionized by electron collision and plasmas are generated. However, the mean free path of electrons with 100 eV energy inside the chamber with argon gas pressure of 10^{-4} Torr is about 1 meter. For efficient plasma confinement, permanent magnets are used to produce a large volume of uniform and quiescent plasma. The maximum plasma density in an uniform large volume confined by the multicusp field in this experiment is found to be about 4.9×10^{9} cm^{-3}.

When the chamber is operated as an ion source, the magnets on one end of the vessel will be removed therefore the plasma density profile in the axial direction will not be uniform. The maximum density is located towards the back plate [3]. Ions generated on the right hand side of this maximum will be pushed toward the plasma electrode. The speed of these ions when they enter the sheath is greater or equal to the ion sound speed ($\sqrt{KT_e/M_i}$) where M_i is the mass of the ion, K is the Boltzmann constant, and T_e is the electron temperature. The relationship between the ion current density J_i arriving at the plasma electrode and the maximum plasma density n and the ion sound speed can be expressed as [14]

$$J_i = \alpha n e \sqrt{KT_e/M_i} \qquad (1)$$

Once J_i is determined, the extraction geometry can be designed by using the Child-Langmuir space-charge limited current flow equation. We measured the proportionality constant α for heluim, argon and xenon.

2. Experimental Technique

A schematic diagram of the experimental setup for the positive ion measurement is shown in Fig. 2. The plasma generator is a thin-walled (2 mm) cylindrical stainless steel chamber (31.2 cm diameter by 42.5 cm long). The chamber wall is surrounded externally by 632 of ceramic permanent magnet buttons ($B_{max} \approx 2.2$ kG) in a full-line cusp configuration [2]. The plasma is generated by electrons emitted from a tungsten filament (1 mm diameter by 20 cm long) biased at −40 V with respect to the chamber wall (anode). This filament extends approximately 7 cm into the magnetic field-free region and the input power was about 650 watts. The operating gas (helium, argon, xenon) pressure inside the chamber was 3.8×10^{-4} Torr. Plasma parameters and density profiles were obtained using movable single Langmuir probes 0.15 mm in diameter and 10.0 mm long.

An electrostatic probe control and data acquisition system has been presented elsewhere [11]. They shall briefly be described here. The system consists of 4 subassemblies, excluding power supplies. This includes an IBM/PC printer port to multiport translator, a dual DAC (digital to analog) unit, a multi-channel, programmable gain, 13-bit bipolar ADC, and a dual power amplifier module. The DACs are 12-bit bipolar serial converters (+/− 11 bits) each which drive one power amplifier. The power amp is capable of +/− 30 V and directly drives the plasma probe through an RG-58 coaxial cable. On the power amp board is a current monitoring resistor and a differential amplifier across it. Each of the two channels has one current sense voltage and one load voltage signal sent to channels on the ADC board.

The programming language chosen was Visual Basic for Windows due to its ease of producing a GUI (graphical user interface) for the operator and its flexibility to incorporate libraries from other programs such as assembly language. Data is stored onto disk in three

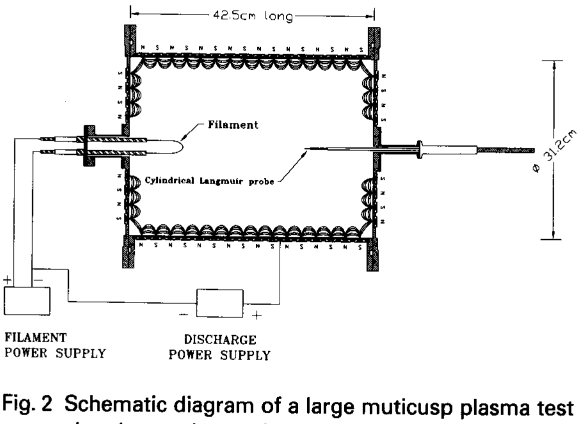

Fig. 2 Schematic diagram of a large muticusp plasma test chamber and experimental set up for positive ion measurement.

formats; native (used for the local plotting program), Sigma Plot and comma delimited format (for exporting into a database or spreadsheet program). This allows more sophisticated analysis of the data off-line. Within the virtual control console is a set of digital meter displays that reflect the conversion voltages and currents of the probes in real time and a graphical plotting display that is updated at the end of the run. The system has the ability to operate in playback mode, that means any data run can be replotted at any time without using an external plotting package. There are also controls for setting full scale of the current axis. The ranges available are, 100 mA f.s, 10 mA f.s, 1 mA f.s, and .1 mA f.s (bipolar). Since the ADC is +/− 12 bits that means a resolution of 1/4096 within the selected full scale for the probe current. The probe voltage conversion is locked at a resolution of 2.4 mV due to the range it operates in normally is high.

The electron density n_e was determined also by using the single Langmuir probe technique. We determined the electron saturation current I_e^*, and the electron temperature T_e from the slope of a semilog plot of the probe current I_e *vs.* the probe bias voltage V_p [10]. The electron density of mass m_e was calculated from the following equations.

$$n_e = \frac{1}{e}\left(\frac{I_e^*}{S}\right)\sqrt{\frac{2\pi m_e}{KT_e}}$$

$$= J_e \frac{1}{e}\sqrt{\frac{2\pi m_e}{KT_e}} \qquad (2)$$

where S is the probe collection area, and J_e is the electron current density. This procedure is easy to use and can give quite reproducible results [11]. We are assuming that at the plasma boundary, the electron density equals the ion or plasma density n [12,13].

The proportionality constant α was determined from equation (1) with an operating discharge voltage V_d set at 50.0 V and a bias voltage V_B at 50.0 V. The experimental set up for determining α is shown in Fig. 3.

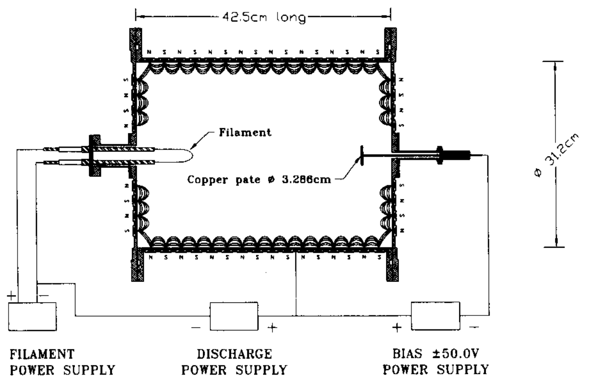

Fig. 3 Schematic diagram of an experimental setup for the measurement of the proportionality constant α (see text).

3. Experimental Results and Discussion

Fig. 4 shows the axial density profile of helium ion (He^+), and argon ion (Ar^+). In this measurement, the discharge current I_d was set at 0.5 A, the discharge voltage V_d was 40 V, and 50 V, and the gas pressure inside the chamber was 3.8×10^{-4} Torr.

Fig. 5 displays the radial density profile of He^+ and Ar^+. The operating condition was the same as in the measurement of the axial density profile.

Fig. 6(a) shows the ion density of He^+, and Ar^+ as a function of discharge voltage. In this measurement, the discharge current was 0.5 A, and the gas pressure inside the chamber was 3.8×10^{-4} Torr. Fig. 6(b) shows the He^+ and Ar^+ density as a function of discharge current for a discharge voltage of 50.0 V and the gas

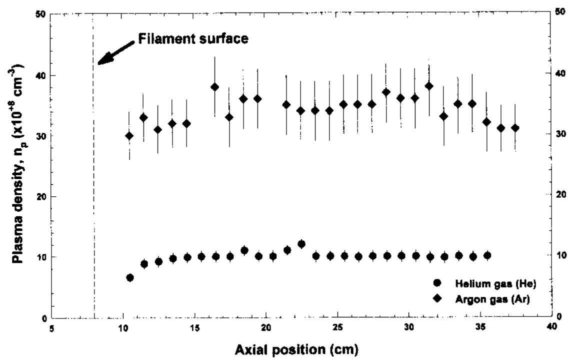

Fig. 4 A typical axial ion density profile of helium and argon.

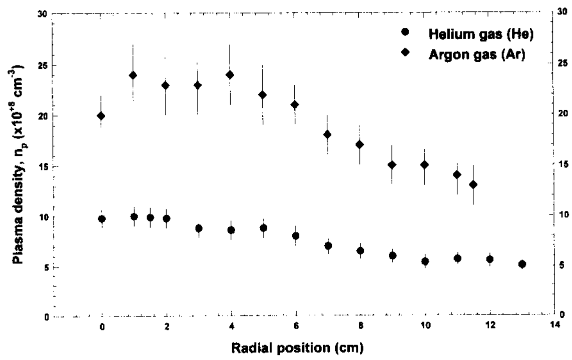

Fig. 5 A typical radial ion density profile of helium and argon.

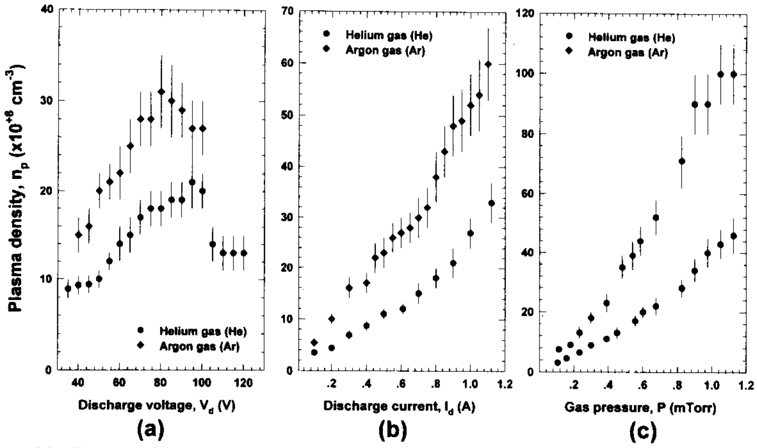

Fig. 6 Plot of ion density of helium and argon versus (a) the discharge voltage, (b) the discharge current, (c) the neutral gas pressure.

pressure inside the chamber of 3.8×10^{-4} Torr. The discharge current was kept relatively constant during the measurement by changing the filament current. Fig. 6(b) shows the He^+ and Ar^+ density as a function of neutral gas pressure operating with a discharge voltage of 50.0 V and a discharge current of 0.50 A.

Table 1 shows the α factor values determined using helium, argon, and xenon ions, with an operating discharge voltage of 50.0 V and a bias voltage of 50.0 V.

The plasma confinement of the axial density profile for argon and helium ion are fairly uniform. We also found that the plasma potential exhibits a similar uniform profile. These profiles are symmetric because of a symmetric line cusp magnetic confinement around the chamber. This relative uniform ion density profile in the axial direction is to be expected since the vessel is enclosed by magnets at both ends. When the magnets on one end are removed the density profile is not uniform with a maxima located towards the end plate as shown by the work of Leung *et al.* [3]. The radial density profiles are uniform up to about 6 cm before dropping off to about two-third of the maximum value at a distance of about 12 cm from the axis of the chamber.

Table 1 The proportionality constant α (see text) as determined using helium, argon and xenon gases.

Ion	Plasma parameters at I_d = 0.50 A, V_d = 50.0 V, and V_B = -50.0 V					α factor
	T_e (eV)	J_e ($\times10^{-3}$ A/cm^2)	n ($\times10^{+8}$ cm^{-3})	I_B (mA)	J_i ($\times10^{-5}$ A/cm^2)	
He^+	1.44	1.55	4.8 ± .6	0.38	1.92	0.42 ± .07
Ar^+	1.43	8.37	26. ± 3.	0.90	4.55	0.59 ± .08
Xe^+	1.40	15.60	49. ± 6.	0.73	3.69	0.46 ± .06

For a dc discharge plasma confined by the magnetic multicusp field operated under the above conditions, the plasma density in an uniform large volume is found to be between $4\times10^8 - 4\times10^9$ cm^{-3}.

From Fig. 6(a) we can see that the rate of plasma production is maximum when the primary electrons have an initial energy approximately equal to 80 eV for both gases. The same result is also obtained from other gases such as hydrogen and nitrogen [3, 15]. By increasing the discharge current, the plasma production rate and the probability of ionization increases. Fig. 6(b) shows that the rate of plasma production is highest when the discharge current is above about 1 A and the discharge voltage was 60 V. For a large source chamber the plasma production rate increases significantly with the neutral gas pressure.

The measured proportionality constant α for He, Ar, and Xe gases is $0.42\pm.07$, $0.59\pm.08$, and $0.46\pm.06$, respectively. These values are in agreement with the value (0.49) calculated by Forrester [12], if we assume that the electron density equals the ion density. This assumption is reasonable since we use the maximum values of ion density in the determination of the values of α. The available ion current density, ion species and the uniform plasma region are important parameters for proper extracting and accelerating beam of ions.

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