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Effect of Metal Plate of Variable Area on Plasma Parameters in Multi-Dipole Discharge

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Abstract. This article reports a novel method of control of plasma parameters by using grounded stainless steel plate of varying diameters in multi dipole filament discharge plasma. On increasing the diameter of the grounded plate, the exposed area of the plate to the plasma increases and hence bulk plasma density decreases along with an increase in plasma electron temperature and plasma potential. The reverse trends of variation in parameters are observed when the diameter of the grounded plate becomes smaller.

KEY WORDS: Filament discharge, Electron temperature, Plasma potential.

1 Introduction

The effectiveness and efficiency of plasma-based processes largely depend on the precise control of key parameters, such as plasma potential, plasma density, and electron temperature. Different electron energy levels influence the production rates of various active species. Therefore, electron temperature (T_e), which is an important parameter in plasma applications, plays a significant role in regulating reaction rates [1]. Furthermore, electron temperature and plasma density are essential parameters for investigating elementary particle processes and collective plasma phenomena in weakly ionized plasmas [2].

Moreover, addressing the current and emerging challenges in nanoscale microelectronic fabrication requires the development of advanced plasma etching techniques. These techniques demand precise control over plasma parameters and etching characteristics. Effective control of the electron energy distribution (EED) and ion energy distribution (IED) provides two important approaches to achieving this objective. The EED determines several plasma properties, including electron temperature ((T_e) and plasma density, and influences the rates of electron-impact reactions responsible for generating reactive species from feed-

stock gases [3]. Various techniques have been developed to control plasma parameters.

Biased grids are among the most commonly employed techniques for controlling plasma parameters. Kato et al. [2, 4] investigated the control of electron temperature in plasma passing through a mesh grid positioned between the discharge and downstream regions. Their studies demonstrated that the grid-biasing technique can effectively regulate electron temperature, even when the electrical conductivity of the grid is reduced due to the deposition of dielectric diamond-like carbon films [5]. Similarly, Bai et al. [6–8] employed a mesh grid to control electron temperature in the diffuse region of an inductively coupled plasma.

A new technique, adding argon or helium into nitrogen plasma was used to regulate the electron temperature was used by Zeng-De and Yi-Kang [1]. Haas and Braithwaite [9] influenced the electron temperature through the introduction of energetic electrons into the tail of a background Maxwellian. Hayashi [10] used a magnetic filter to achieve a reduction of electron temperature in a RF plasma. Recently, Liu et al. has reported an external control method for Electron energy in a plasma reactor having two separately powered ICP sources in a tandem geometry and separated by a mesh grid [11].

Mishra et al used negatively biased grid to control plasma parameters in a diffuse plasma produced in a double plasma device [12]. Also similar to Hershkowitz et al. [13], they have applied a mechanical methods to vary the diffused plasma parameters of a hot filament plasma, confined by multidipole magnetic cage systems and produced in a DP device [14]. In another experiment, they have also used remote electron showers to vary the plasma parameters in the discharge chamber [15] and to control the hot to cold electron density ratio of a plasma having bi-Maxwellian electrons, they have used electro statically plugged multidiole magnetic cage system [16]. Mishra et al. have also shown that plasma parameters can also be controlled by using a movable ion sheath [17]. Recently they have reported the effects of a movable metal plate on the plasma parameters where the metal plate was positive biased to act as a part of discharge, viz the anode [18].

The experiment is carried out in a Double Plasma Device equipped with two multi-dipole magnetic cage for independent plasma production by hot filament discharge method. A multi-dipole cage is a set of alternating rows of north and South Pole permanent magnets placed around the surface of discharge in a cylindrical shape. The alternating rows of magnets generate a line cusp magnetic configuration in which the magnetic field strength is highest near the magnets and decays with the distance to the center of the cage. So, the bulk plasma volume is virtually magnetic field free, but a strong field of about 0.1 T usually exists (as estimated in our case) near the cage wall, inhibiting plasma loss and leading to an increase in plasma density and uniformity. The magnetic field distribution with the distance from the surface of the cage was presented in Ref. [19].

In this experiment, we have applied a novel method to control parameters of filament discharge plasma of a multi-dipole device. To study the variation of plasma parameters in the bulk region of plasma, we used grounded stainless steel plates of three different diameters. Till date, metal plates are used for plasma parameter variations, but effect of varying exposed areas of the plates on the parameters are reported for the first time. All the three stainless steel plates are of same thickness and kept at the fixed position inside the magnetic cage of the device. The variations in plasma parameters with the diameter of the S.S plates are observed. The observed results can be interpreted on the basis of different rates of plasma diffusion loss to the metallic plates with the change in exposed are of the plates.

2 Experimental Setup

The experiment was conducted in one of the two multi-dipole cages of an existing double-plasma (DP) device. The fully lined cusped magnetic confinement cage is cylindrical in shape, with a length of 30 cm and a diameter of 25 cm. The inner surfaces of the cage are lined with 14 rows of permanent magnets. Permanent strontium ferrite magnets are housed inside stainless-steel square pipes and arranged in an alternating north-pole–south-pole configuration.

A schematic representation of the magnetic field configuration of the cage is presented in Ref. [20]. This arrangement of magnets produces closed magnetic field lines along the surfaces of the magnetic rods, generating a magnetic field of approximately 1 kG near the walls. The magnetic field strength decreases rapidly towards the centre, leaving the central plasma region essentially free from magnetic fields.

The base pressure of the vacuum chamber is maintained at 5×10^{-6} mbar using a combination of rotary and diffusion pumps. The operating pressure of 3×10^{-4} mbar is maintained by introducing argon gas into the chamber.

Plasma is generated using the filament discharge technique, in which four sets of tungsten filaments serve as the primary electron emitters. These heated filaments act as cathodes, while the grounded magnetic cage serves as the anode. Argon plasma is produced by applying a suitable DC discharge voltage of 60 V (V_D) between the filaments and the magnetic cage. The discharge current is maintained at 50 mA throughout the experiment.

A schematic diagram of the experimental arrangement is shown in Figure 1. Three grounded stainless-steel (SS) plates, with diameters of 24 cm, 16 cm, and 8 cm, are used inside the chamber. Each plate is grounded and positioned at the opposite end of the cylindrical magnetic cage. The plate is maintained at a fixed distance of 25 cm from the cage, corresponding to a distance of 20 cm from the Langmuir probe position.

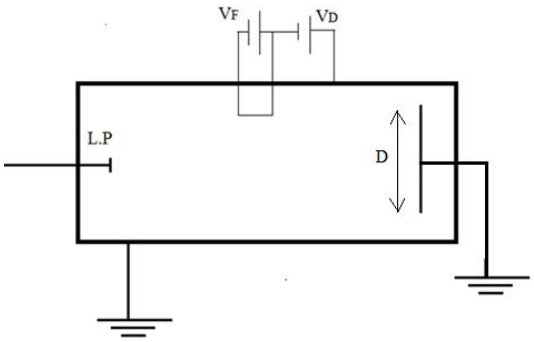


Figure 1. Schematic diagram of experimental setup. V_F and V_D represents the filament voltage and the discharge voltage respectively. D is the diameter of the grounded plate and L.P is the Langmuir probe.

A cylindrical molybdenum Langmuir probe, having a diameter of 1 mm, is used to measure the plasma parameters. The probe is positioned at a radial distance of 10 cm from the filaments. The measured plasma density lies in the range of 10^{14} m^{-3}, while the electron temperature ranges from 2 to 4 eV. The plasma potential is determined from the maximum of the first derivative of the probe characteristics [14].

3 Results and Discussion

Initially, a grounded stainless-steel plate of 24 cm diameter is positioned near the end of the magnetic cage, and the Langmuir probe characteristics are recorded in the bulk plasma region of the chamber. Subsequently, the 24 cm plate is replaced successively with plates of 16 cm and 8 cm diameters, without changing the position of the plate or the Langmuir probe. The corresponding probe characteristics are recorded for each configuration.

Figure 2 illustrates the variation in plasma density with decreasing diameter of the grounded plate from 24 cm to 8 cm. It is observed that the plasma density increases as the diameter of the grounded plate decreases.

In the filament-discharge low-density plasma considered in this experiment, where cusp magnetic fields are employed, plasma production through ionization by primary electrons and diffusion losses of electrons towards the cusp regions occur simultaneously. The plasma density is maintained through a balance between these two processes.

The introduction of an additional grounded plate modifies the diffusion losses of primary electrons towards the plate, thereby influencing the plasma density. It is observed that the plasma density increases as the plate diameter decreases from 24 cm to 8 cm. This enhancement in plasma density can be attributed to the

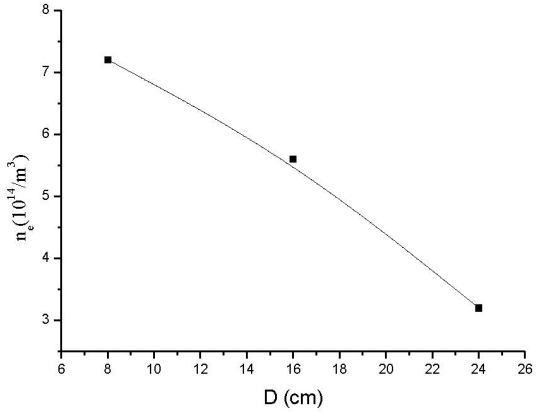


Figure 2. Variation of plasma density (n_e) with diameters (D) of the plates.

reduction in the exposed surface area of the plate. Consequently, the diffusion loss of primary electrons decreases, leading to an increase in plasma density.

Figure 3 illustrates the variation in the floating potential of the plasma as the diameter of the grounded plate decreases from 24 cm to 8 cm. It is observed that the floating potential decreases (becomes more negative) with decreasing plate diameter. This clearly indicates that a reduction in the exposed surface area of the plate to the plasma affects the floating potential.

The decrease in the plate diameter reduces the number of primary electrons lost to the plate, allowing a greater number of primary electrons to remain in the bulk plasma region. This increase in the population of primary electrons contributes to making the floating potential more negative.

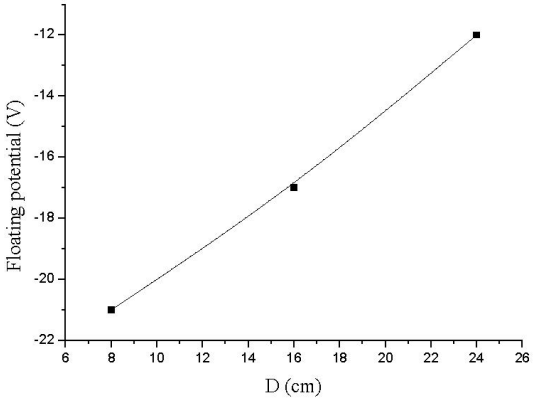


Figure 3. Variation of floating potential with diameters (D) of the plates.

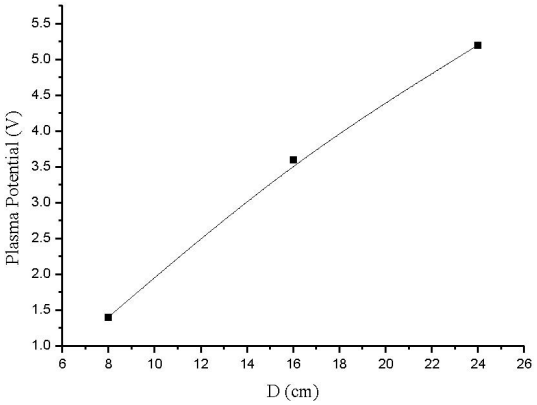


Figure 4. Variation of plasma potential with diameters (D) of the plates.

Figure 4 illustrates the variation in plasma potential with decreasing plate diameter from 24 cm to 8 cm. It is observed that the plasma potential decreases as the exposed area of the grounded plate is reduced. This reduction in plasma potential can be attributed to the increased abundance of primary electrons in the bulk plasma region resulting from the reduced exposed area of the grounded plate. The increased population of energetic electrons enhances the electron-rich nature of the plasma, thereby influencing the plasma potential and causing it to decrease.

Figure 5 shows the variation in electron temperature (T_e) with the diameter of the grounded plate. The electron temperature decreases as the plate diameter decreases from 24 cm to 8 cm. This reduction in electron temperature is associated with the increase in plasma density, as shown in Fig.2. The observed trend

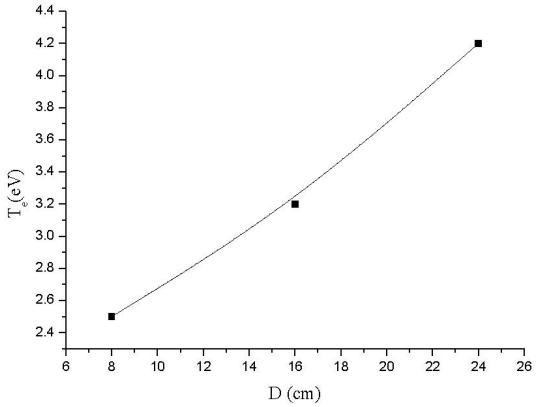


Figure 5. Variation of the electron temperature (T_e) with diameters (D) of the plates.

may be explained by the increase in ionizing collisions, which results in a reduction in the average electron energy and, consequently, the electron temperature. Furthermore, the variation in electron temperature may also be associated with changes in the plasma diffusion loss rate, since the diffusion rate is proportional to the square root of the electron temperature [14].

The reverse trend in plasma parameter variations is observed when the experiment is initiated with the smaller grounded plate (8 cm) and the plate diameter is progressively increased to 24 cm. Although the experimental results presented here correspond to an operating pressure of 3×10^{-4} mbar, similar trends in plasma parameter variations are also observed at two other operating pressures of 6×10^{-4} mbar and 9×10^{-4} mbar.

4 Conclusion

In this study, grounded plates of three different diameters are employed to control the loss of primary electrons within a multi-dipole magnetic confinement cage. The plate diameter determines the effective surface area available for electron loss, thereby influencing the plasma parameters. An increase in the plate diameter provides a larger effective loss area for electrons, which subsequently modifies the plasma characteristics.

The observed variations in important plasma parameters, particularly electron temperature and plasma potential, demonstrate the possibility of controlling weakly ionized plasma through the appropriate selection of grounded plate dimensions. Such control of plasma parameters may have practical applications in plasma etching and other plasma-processing techniques, where maintaining suitable plasma conditions is essential for achieving the desired processing environment.

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