A Comparative Study on the Variation of Plasma Parameters by a Movable Biased Metal Plate

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Abstract: This article reports a comparative study on the variation of plasma parameters like Plasma electron temperature, plasma potential and density etc. in a Double Plasma Device. Plasma here is producedin the Target section of the device by applying a discharge voltage between the electron emitting filaments (in source) and the grounded target magnetic cage. The changes in plasma parameters are monitored in two ways, first by changing position (mechanical means) of a negatively biased plate and next by change in electrical biases(electrical mean)applied to the same plate by keeping it at a fixed position inside the Target magnetic cage of the Device. It is observed that plasma parameter variation in the case of "Electrical mean" is more pronounced. That is; the bias on the plate has dominant role in controlling high energetic electron flux that come from Source to Target to cause ionization in the target section, rather than the exposure area of the target magnetic cage to trap the energetic electrons.

Introduction:

The effectiveness and efficiency of the plasma based processes depend on the degree of control over relevant parameters such as plasma potential, plasma density and electron temperatures. Various electron energies correspond to different productivities of active species. Thus the electron temperature (T_e), an important parameter in these applications, can directly regulate the various reaction rates (1). Also the parameters like electron temperature and plasma density are essential to study dependencies of different particle elementary processes and plasma collective phenomena in weakly ionized plasmas. (2).

Most importantly, in order to meet present and upcoming challenges for microelectronic fabrication in nano sizes,advanced plasma etching techniques are required, necessitating tighter control over plasmaparameters and etch characteristics. Better control of the electron energy distribution (EED) andthe ion energy distribution (IED) are two ways to achieve this goal. The EED controls plasma properties such as electron temperature (T_e) and plasma density, as well as the rates of electronimpact reactions that generate reactive species from feedstock gases.(3)Till date, different techniques have been adopted to control plasma parameters.

Biased grids are most commonly used in controlling plasma parameters. Kato et.al (2,4) performed experiments on controlling the electron temperature on plasmas passing through a mesh grid from a discharge region. They have also shown that grid bias method can be used for temperature control, even if the conductivity of the grid is reduced by the deposition of a dielectric diamond like carbon films (5).Bai et.al also used mesh grid to control the electron temperature in the diffuse region of a inductively coupled plasma (6-8)

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 multi-diolemagnetic cage system.(16). Mishra et.al have also shown that plasma parameters can also be controlled by using a movable ion sheath. (17)

In a Double Plasma (DP) device, a quiescent and unmagnetized plasma can be produced using multidipole principle (18). A DP device consists of a Source and Target, which is separated by a mesh grid. Primary electrons which produce the plasma by ionizing the neutral gas are emitted by the hot filaments installed inside the chamber. Here the DC plasma is created in a region (target) separated from the main electron emitting region by a fine mesh grid.In this scheme of plasma production, plasma is produced in the target by extracting high energetic electrons from the source side filaments to the grounded target magnetic cage by applying a discharge voltage in between them and by using a retarding potential (for the electrons) to the source magnetic cage. This mode of plasma production is similar to that produced by an electron beam.The use of negative bias to the source magnetic cage imparts a directed motion to the electrons of the source magnetic cage towards the Target and hence the plasma is mainly appeared in the Target section of the device. (19). The electron beam excited plasma has some remarkable characteristics such that it can be operated with direct current and the electron beam density and energy are controlled independently by discharge current and accelerating voltages, respectively due to the constant voltage and constant current characteristics. Therefore electron temperature, plasma density as well as sheath potential are easily controllable compared with other plasma sources.(20) Studies on electron beam excited plasma discharges also reveal that the thermal beam component has a significant role in determining process conditions (21,22,23) . In our experiment, the plasma density is one order higher than the diffuse plasma density (14) and more stable and noise-free quiescent plasma may be expected to be present under such a plasma production mode of a DP device.(19).

In this experiment, we have presented two different means (methods) to control plasma parameters. The first one, we call it -Mechanical means, where we have used a negatively biased metallic plate in the target section of the device at various positions by pulling it axially, in order to vary the plasma parameters in that region. In the second case, we termed as Electrical means, the metallic plate is kept at a fixed distance inside the target magnetic cage and the negative bias applied to it are varied in steps. Both ways plasma parameters can be controlled or varied, but it is observed that the change in negative bias to the plate is more effective in changing the plasma parameters than by the variations of the position of the fixed negatively biased plate inside the target magnetic cage.

Experimental procedure:

The experiment is carried out in a DP device consisting of two identical cage structures of 35 cm length and 25 cm in diameter, which are made up vacuum-sealed rectangular tubes containing small permanent magnets for surface plasma confinement. The two cage structures are electrically isolated from each other.A stainless steel mesh grid of 80% transparency separates the device in to two regions viz, source and target. A schematic diagram of the experimental setup is shown in fig.1(a). The schematic diagram of the surface magnetic field produced by the multidipole magnets and the location of the filaments inside the source magnetic cage are shown in fig.1(b)

The base pressure of the device is $4x10^{-6}$ mbar. Hot electron emitting filaments (cathode) are placed inside the source magnetic cage. No filaments are placed in the target section. The plasma is produced by electron bombardment of neutral argon gas at $5x10^{-4}$ mbar pressure by applying a DC voltage between the hot filaments (cathode)and target magnetic cage (anode), while keeping the source magnetic cage bias at a negative potential below its floating potential. Electrons emitted from the hot filament (cathode)in the source ionize the background gas on their way to the anode (target magnetic cage). The discharge voltage (V_D) and the discharge current (I_D) are fixed at 60 V and 80 mA respectively. A stainless steel plate of diameter 20 cm and thickness 1 mm is inserted in the magnetic cage and asthere is no filament holder in the target section of the device, hence this plate can be moved axially both inwards or outwards. A negative bias is applied to the plate and as per the experimental requirement, the bias can also be varied.

A cylindrical Langmuir Probe of 1 mm diameter is placed radially at the centre of the target section, 3 cm away from the separation grid to measure target plasma parameters. The measured plasma density is around $10^{16}m^{-3}$ and the plasma electron temperature is in the range of 1-4 eV.

Results and discussions:

Mechanical Method:

Langmuir probe characteristics are recorded in the target section by placing the negatively biased plate at different distances from the fixed probe position. The distance between the probe and the metallic plate position is denoted by D. The separation grid is kept floating throughout the experiment.

Fig.2 shows the variation of plasma density as obtained from the probe data taken at different positions of the plate. It is observed that plasma density is increased with a fall in plasma electron temperature when D increases. First the negatively plate at -70V is kept at 10 cm away from the grid and the distance now increases gradually in steps of 5 cm. Actually plasma density is determined by a balance between the plasma production rate and the diffusion loss rate in a low density plasma as in our experiment. The creation rate of target plasma density depends on the hot electron flux from the source section to the target section. As the plasma density is kept constant by maintaining a fixed discharge current and also the separation grid is at floating potential, so a fixed amount of electron flux can enter the target section. The negative bias on the plate prevents most of the electrons to their diffusion loss at the plate and the variations in plasma density is mainly due to the change in the exposed area of the confining magnetic field of the target section with different positions of the plate(14). When the plate is moved away from the probe position, relatively large portion of the magnets are exposed to the electrons, so the electrons are better trapped and hence they will cause more ionizing collisions and as a result the plasma density increases. The electron temperature variation (fig 2) is inverse in nature to the plasma density variation with plate position and this is explainable on the basis of the electron energy loss in increased ionizing collisions. This decrease in plasma electron temperature in the target may also be explained on the basis of the trend of plasma potential variation with the negatively biased plate position (fig 3).The plasma potential is measured from the first derivative of probe characteristics (19). As the distance of the plate from the Langmuir probe increases, morenumber of high energetic electrons that come from source to target can be trapped by multi-dipole magnetic field and they will make the bulk region of plasma electronegative (electron rich) and the negative plasma will repel or retard (19) the electrons and thus plasma electrons loss their energy. This may be another explanation for decrease in electron temperature with the plate distance variation. Pal et al have shown that the plasma potential decreases to a more negative value when the injected energy ofan electron beam in to the target from the source section of a DP device is increased.(24)

Electrical Method:

In this method, the plate is kept at a fixed distance from the grid inside the target chamber and the negative biases applied to it are varied in steps. The Langmuir probe characteristics are taken first at -40V, then at -35,-30 and -25 V respectively by keeping it at a distance of 20 cm from the separating grid. It is observed that the target plasma density increases with a fall in plasma electron temperature with decrease in negative bias to the plate from -40 to -25 V. This is shown in fig 4. At a higher negative bias to the plate, the electrons of the source section find arepelling field in the target region, but when the negative bias to the plate decreases, the hot electron flux from source to target increases and this inturn may cause more ionizing collisions in the target section and this will increase the plasma density. This increase in plasma density is also associated with a decrease in plasma electron temperature, shown in fig 4. The plasma electron temperature decreases because of the increase in ionizing collisions with the neutral. Though same trend of plasma density and temperature change is noticed with a increase in distance (D) or decrease in negative bias (V_p) applied to the probe, the effect is more pronounced in the later case, i.e in Electrical mean. The change in T_e is just 0.4 eV, when 'D' increases by 10 cm, while it changes by 0.9 eV when the negative bias applied to the plate changes by 5 V.

The trend of change in plasma potential is shown in fig 5.The plasma potential, which is obtained from the first derivative of probe characteristics, also observed to get decreased, because of increase in number of electrons with the decrease in negative bias applied to the plate. It is also observed that plasma potential variation is more in this case compared to the previous case of mechanical means.

Conclusion:

In conclusion, we have presented and hence compared two means through which plasma parameters can be controlled in a weakly ionized discharge plasma of a double plasma device. This mode of plasma production has a resemblance to that of a low energetic electron beam excited plasma. Here plasma is produced in a region which is separated from the main hot filament emitting region by a floating grid and a negatively biased stainless steel plate is used to control the plasma parameters. The first method involves the movement of a negatively biased plate inside the target magnetic cage and in the second case, the plate's movement is restricted in a fixed position and its negative biasing is varied. Both ways the parameters can be shown to be varied, but the plasma parameters control by the second method is observed to be more effective. That is; the bias on the plate has dominant role in controlling high energetic electron flux that come from source to target to cause ionization in the target section, rather than the exposure area of the target magnetic cage to trap the energetic electrons. This, in a way shows that though cusped magnetic fields are used to trap the high energetic electrons for plasma density enhancement or the variation in cusped magnetic area may be a factor for plasma parameter variation, but a desired plasma parameters may be acquired more suitably and effectively by using a variable negatively biased plate in the vessel itself.

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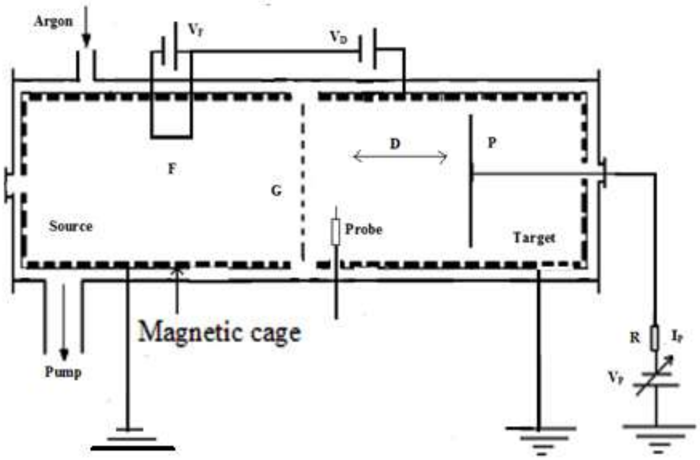
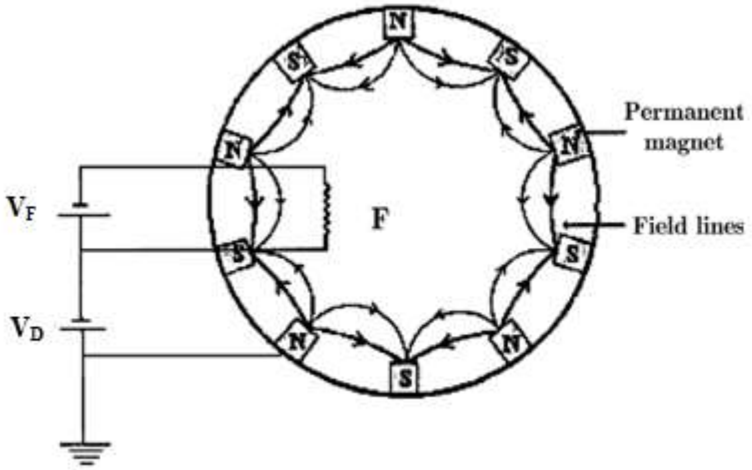


Fig:1(a) Schematic diagram of experimental setup



(b)

Fig.(b) Location of filaments inside the magnetic cage

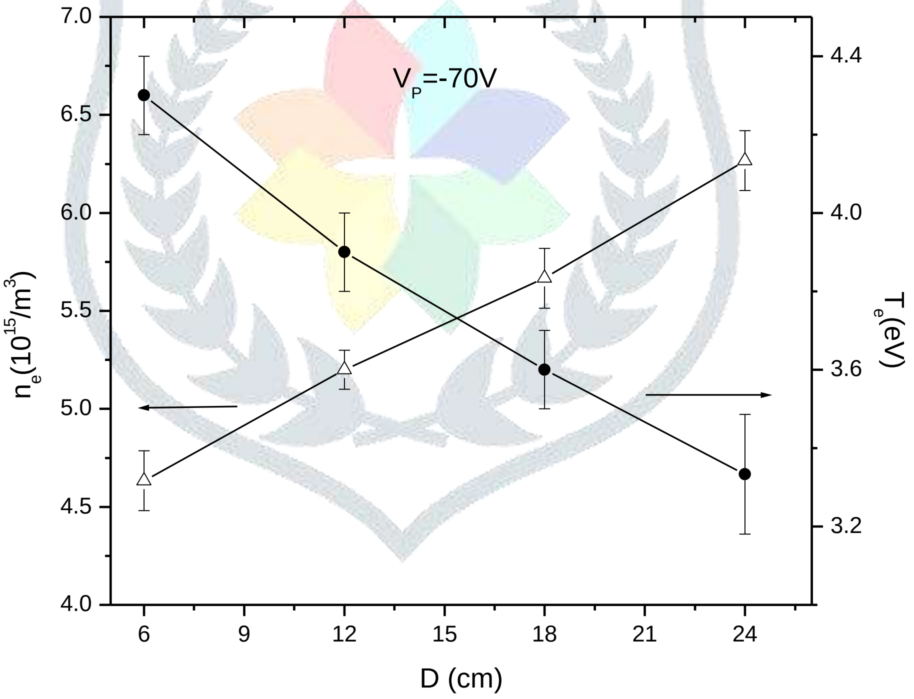
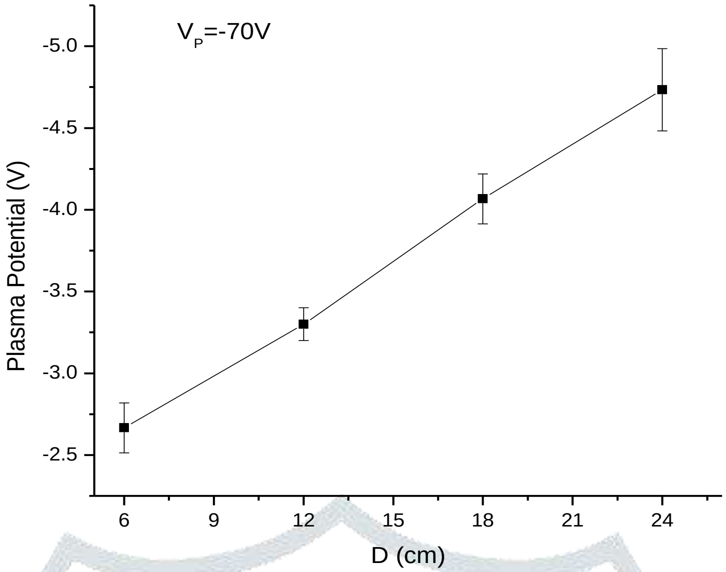


Fig.2 Variation of electron density (n_e) and electron temperature (T_e) with distance D for fixed plate bias V_P=-70V.



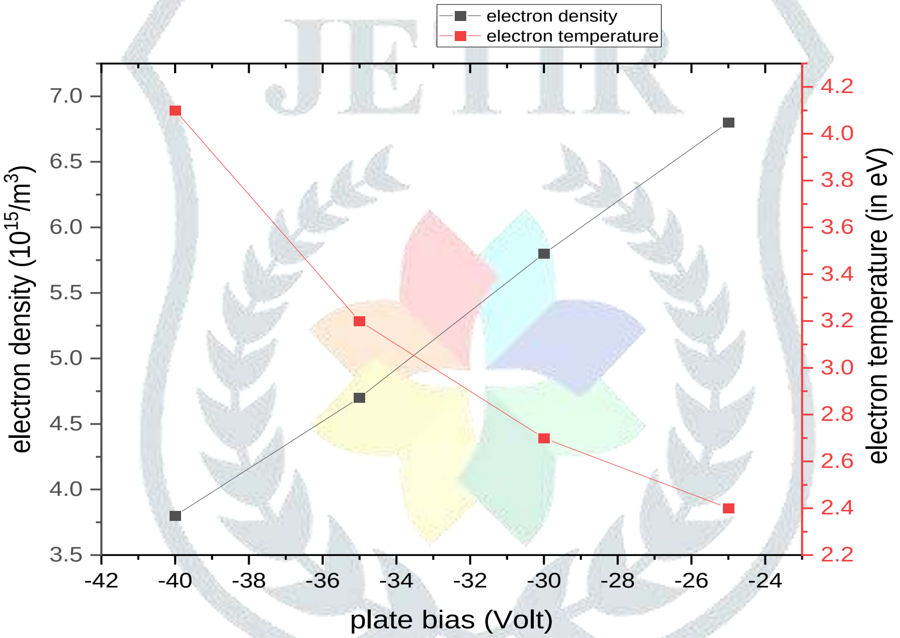


Fig.4 Variation of target plasma density and plasma electron temperature with negative bias to the plate from -40 to -25 V at a fixed Plate position of 20 cm grid

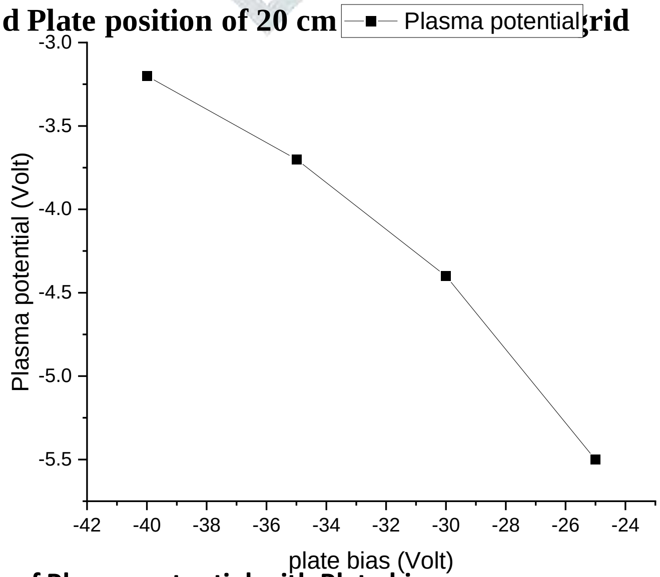


Fig.5 Variation of Plasma potential with Plate bias