EFFECT OF ADDITIONAL CATHODE POTENTIAL ON DIFFUSED PLASMA PARAMETERS IN PRESENCE OF ANODE POTENTIAL

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The variation of diffused plasma parameters with cathode bias voltage has been investigated in presence of fixed anode bias voltage in a double plasma device. The anode we have considered is the multi-dipole magnetic cage where discharge is carried out and additional cathode is the separation grid of the device. The plasma in the nearby region is the diffused plasma. The plasma parameters in the main discharge region are almost independent of the cathode voltage, but electron density and plasma potential are highly sensitive to it in the diffuse region. The velocity of the ion beam, which is supposed to form in the current configuration of the device, varies inversely to the thickness of the ion sheath formed at the cathode.

Key words: sheath, grid, double plasma device, filament discharge.

1. INTRODUCTION

In a Double Plasma (DP) device, plasma is generally produced by hot filament discharge inside multi-dipole magnetic cage [1]. Multi-dipole magnetic cages are used for surface plasma confinement arranged in a line cusp [2]. The primary electrons are emitted by the hot filaments (cathode) and on their way to the cage (anode), they ionize the background gas.

As the name suggest, a DP-device consists of two such magnetic cages (source and target) separated by a mesh grid. Generally, this separation grid is kept at a negative potential in order to cutout the electron coupling between the two cages. This grid is considered as the additional cathode in the present experiment.

If one of the magnetic cages, say source is kept at a higher potential than the target, an ion beam moves from the source to the target region of the device [3]. This can be achieved by biasing the anode of the source region positively with respect to the grounded anode of the target region [4]. In this experiment we shall talk about the anode of source region, which is biased positively. The velocity of this ion beam depends on the potential difference between the two regions [5].

Here, we have produced plasma only in the source region and no direct plasma is produced in the target region. Whenever plasma is produced solely in one region (source) of a DP-device, a low-density plasma is always observed in the other region (target). The plasma in the target region may be due to two reasons, plasma that leaks in through the grid and plasma that is locally produced by the primary electrons [6]. In presence of the negatively biased grid, the plasma electrons being low energetic cannot penetrate the grid and only high energetic primary electrons can enter the target region. The amount of electron flux, which enters the target region (diffused region) from the source region (discharge region) depends on the potential difference [$e\,\Delta V_{SG}= e\,(V_{SP} - V_G)$] that exists between plasma potential in the source region (V_{SP}) and the negative grid bias voltage (V_G) [7]. This potential difference (ΔV_{SG}) acts as the barrier potential for electrons but at the same time it accelerates the ions. This potential difference can be increased either by increasing the source plasma potential or by increasing the negative grid bias voltage.

When the potential difference is increased only by increasing the source plasma potential (V_{SP}), the amount of electrons entering the target region get reduced and simultaneously an ion beam enters the target region. Again, if the potential difference is increased only by increasing the negative grid bias voltage (V_G), mostly background ions are getting accelerated towards the grid and to the target region.

Under both the circumstances, very few high energetic electrons in the source region will be overcome the potential barrier (ΔV_{SG}) to enter the target region, but most of the ions will be accelerated towards the grid and to the target. These ions will enhance the ion space charge layer in front of the negative grid.

In this experiment, keeping the source anode potential fixed, we have increased the negative potential applied to the separation grid, which acts as the cathode in addition to the filaments. The effect of the negative grid bias voltage on plasma parameters such as plasma potential and plasma density have been studied in both the region. The variations in beam velocity and sheath thickness are calculated using the experimental data. The energies of electrons present in the target region are estimated using Langmuir probe. The pattern of *Electron Energy Probability Function* (EEPF) shows that Maxwellian nature of electrons.

2. EXPERIMENTAL SET-UP:

The experiment is carried out in a DP-device consisting of two identical cylindrical multi-dipole cage structure of 35 cm length and 25 cm diameter. These two cages namely source and target are electrically isolated from each other. A stainless steel mesh grid of 24 cm diameter is placed in between the two cages. To place the grid, magnetic rows are removed from one end of each magnetic cage. The highly mobile electrons can easily move from one cage to the other through the grid due to the removal of magnetic filter.

The grid is insulated from the magnetic cages and the chamber wall. The schematic diagram of the experimental setup is shown in Fig. 1.

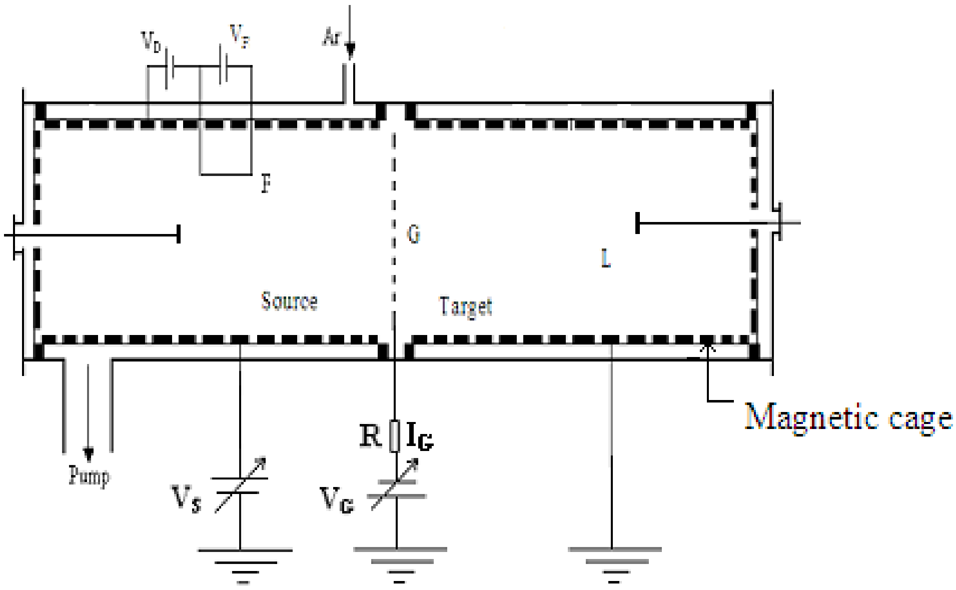

Fig. 1 – A sketch of the experimental set-up. G is the mesh grid, which separates the source and target magnetic cage is biased negatively and act as the additional cathode. The filament F is used as the cathode and the source magnetic cage is used as the anode. V_F, V_D, V_S, and V_G are the filament voltage, discharge voltage, source anode bias voltage and grid bias voltage respectively. R is the resistance across which grid current I_G is measured.

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 maximum near the magnets and decays with distance in to the chamber. So the bulk plasma volume is virtually magnetic field free, but a strong field of about 1 kG exists near the chamber wall, inhibiting plasma loss and leading to an increase in plasma density and uniformity.

The base pressure of the chamber were 4×10^{-6} mbar. The plasma was solely produced in the source region by electron bombardment of neutral argon gas at 5×10^{-4} mbar applying a dc voltage between hot filaments (cathode) and the magnetic cage (anode). The electrons emitted from the filaments ionize the background gas on their way to the magnetic cage. The discharge voltage V_D and the discharge current I_D were fixed at 50V and 40mA respectively. No plasma was produced inside the target and hence no primary electrons were generated in this part. Two plane Langmuir probes of 4 mm diameter were placed both in the source and the target region to measure plasma parameters.

The plasma potential in the source region (V_{SP}) was increased with respect to the plasma potential of the grounded target (V_{TP}) by biasing the anode of the source region positively by a dc potential V_S. The separation grid of the device was kept at a negative potential in order to accelerate the ions and to repel most of the electrons. In this situation a stationary ion beam moves from the source to the target region through the negatively biased grid.

The negative potential applied to the grid was changed by changing the dc potential V_G and the corresponding variation in grid current I_G was measured across a resistance R of 1kΩ. The plasma potential was estimated from the probe voltage at which the first derivative of Langmuir probe characteristics has a maximum.

3. RESULTS AND DISCUSSIONS

At first keeping the source anode bias V_S fixed, Langmuir probe characteristics were recorded in both source and target regions by increasing the negative grid bias voltage V_G. The first derivative (dI/dV) of the probe characteristics recorded in the source region (at fixed $V_S = 10$V) are shown in Fig. 2 (a). It is observed that the peak of these curves appears almost at the same position with a slight increase in their height. It suggests that the source plasma potential (V_{SP}) is almost independent of the applied negative grid bias voltage and there is a slight increase in the electron density. The applied negative grid bias voltages are unable to bring any significant change in the main discharge region.

Another dI/dV curve recorded for $V_S = 20$V are shown in Fig. 3 (a). From the Fig 2(a) and 3(a), it is clear that when V_S is increased keeping V_G constant, V_{SP} increases due to the loss of electrons at the source anode.

The dI/dV curves obtained in the target region for different applied V_G at fixed values of $V_S = 10$V and 20V are shown in Fig. 2(b) and 3(b) respectively. The peak position of these curves shift towards right with a fall in height. It implies that the plasma potential in the target region (V_{TP}) increases with a decrease in electron density. The potential difference ($\Delta V_{SG} = V_{SP} - V_G$) between source plasma potential (V_{SP}) and grid potential (V_G) plays very a important role in controlling the plasma potential and density in the target region.

The observed decrease in target plasma density is due to fact that very few electrons having energy to overcome the potential barrier ΔV_{SG} can enter the target region and as a result less local ionizing collisions take place between the electrons and the ions. The low electron penetration from source to target makes the target plasma potential more positive. Fig. 4 shows the variation of plasma density in both source and target region with the $-V_G$. It is seen that plasma density in the source region remins almost unchanged but in the target region, plasma decreases with the increase in negative grid bias voltage.

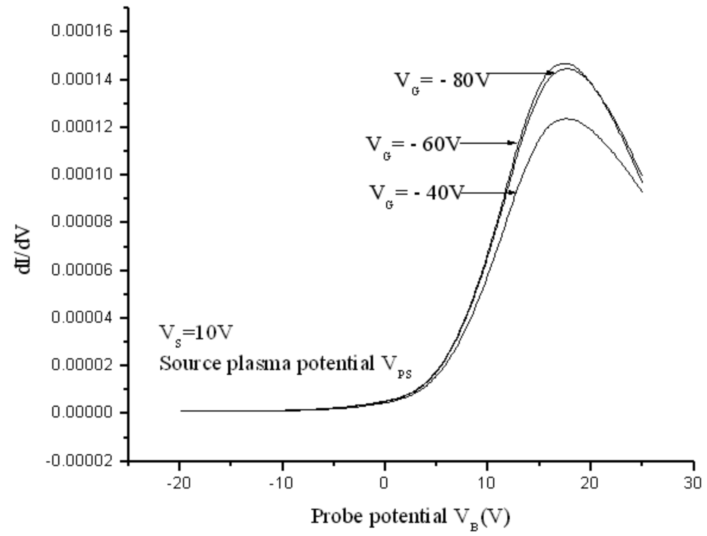

Fig. 2 (a) – First derivative of probe characteristics showing source plasma potential V_{SP} variations for different V_G at fixed V_S= 10V.

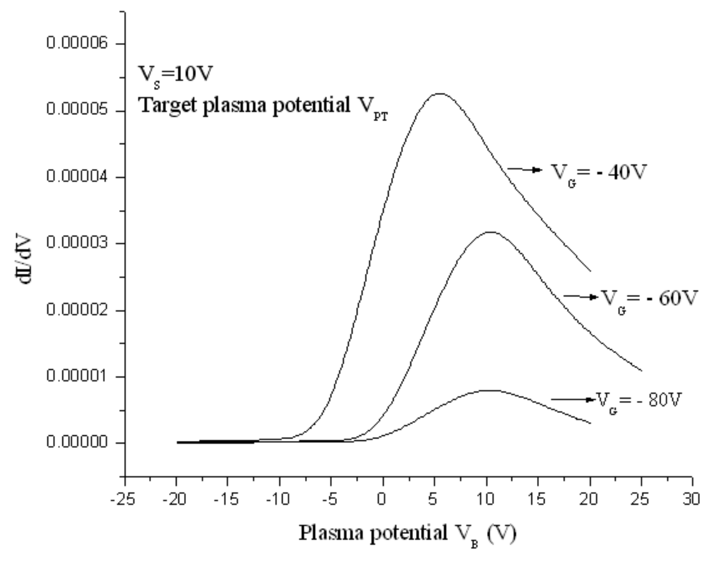

Fig. 2(b) – First derivative of probe characteristics showing target plasma potential V_{TP} variations for different V_G at fixed V_S=10V.

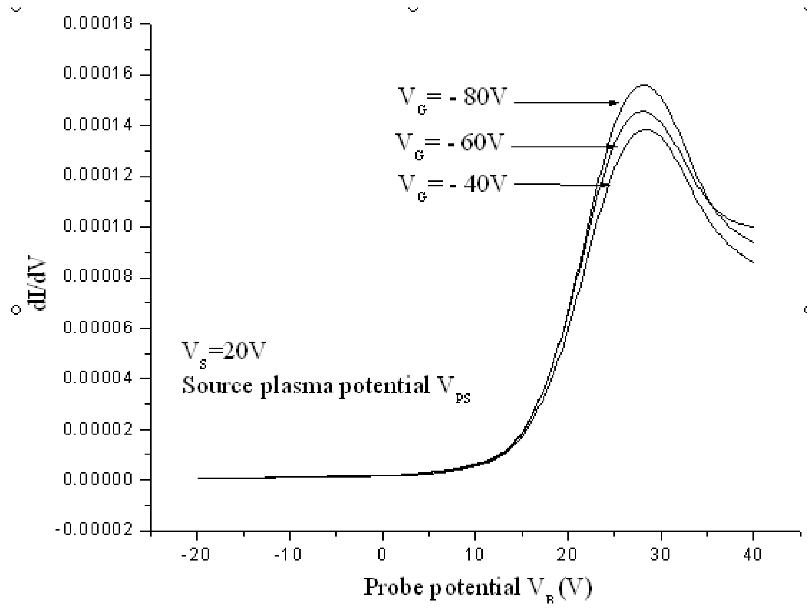

Fig. 3(a) – First derivative of probe characteristics showing source plasma potential V_{SP} variations for different V_G at fixed V_S= 20V.

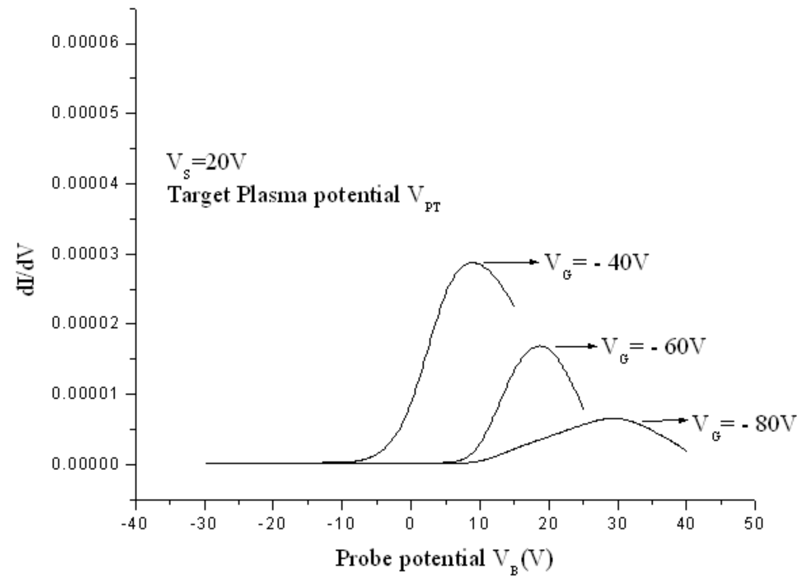

Fig. 3(b) – First derivative of probe characteristics showing target plasma potential V_{TP} variations for different V_G at fixed V_S= 20V.

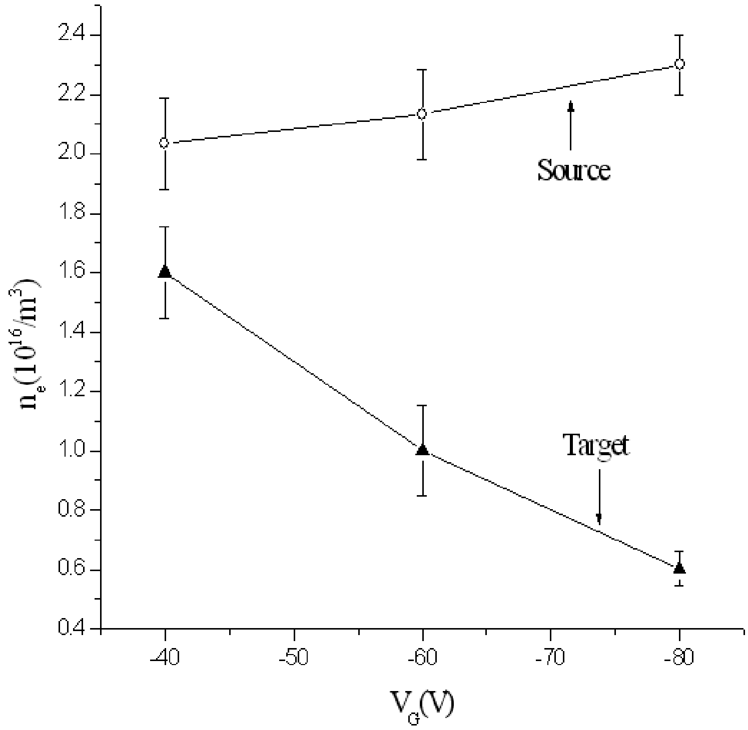

Fig. 4 – Variation of plasma electron density in both source and target plasma region with V_G at fixed V_S= 10V.

From the application of the semi-log plot method to the Langmuir probe data taken in the target region, the electron temperatures can be obtained after the ion current component is removed [8]. This is shown in Fig. 5. Two distributions of electrons are found to present and the magnitude of the currents clearly shows that the density of the high-energy distribution is much lower than that of the low temperature electrons. The high energetic electrons found in the target may be the primary electrons in the source region and low energy electrons are those, which are produced in pairs with ions locally in the target region. The inverse of the slope taken in the respective portion gives the energy of both species of the electrons.

The energy of these electrons found to increase from 21 eV to 30 eV when the grid bias V_G is increase from – 40V to – 80V by keeping fixed at V_S= 10V. In order to investigate the nature of these two electron species, the double derivative of probe characteristics, which is proportional to the *Electron Energy Probability Function* (EEPF) [9, 10] is plotted in Fig. 6. The EEPF exhibits maxwellian pattern, which suggest the maxwellian nature of the electrons present in the target (diffuse) region. The peak of these curves appear almost in the same position which indicates that negative grid bias voltage can not influence much the energy of low energetic electrons.

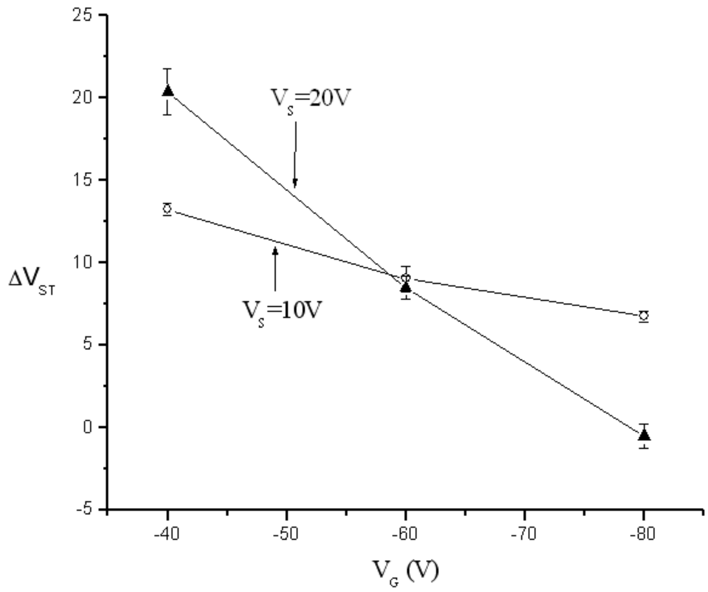

Fig. 5 – A semi log plot of the probe characteristics taken in the target region for different applied grid bias voltage V_G and at a fixed V_S =10V. The plot shows the high and low temperature nature of electrons.

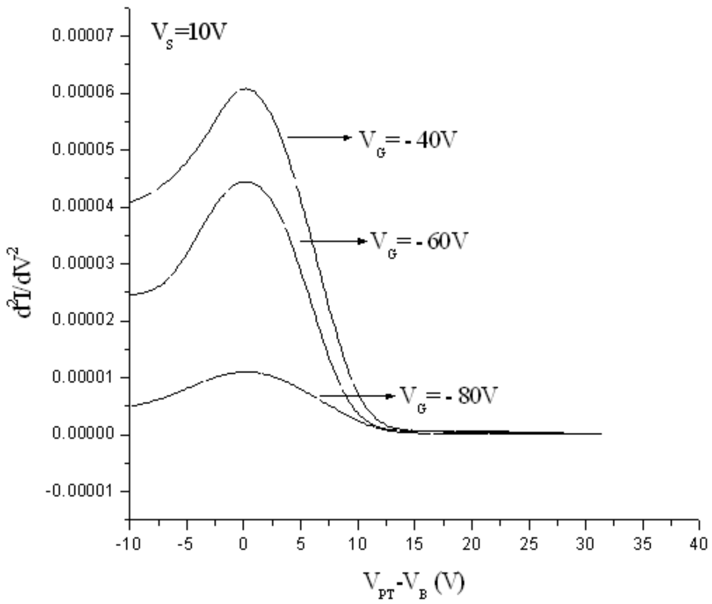

Fig. 6 – The double derivative of the probe characteristics (which is proportional to the EEPF) is plotted for different V_G. Along x-axis, V_{TP}-V_B (which is proportional to the electron energy in the retarding portion of the probe characteristics) is plotted.

In Fig. 7 the difference of plasma potential between source and target region $\Delta V_{ST} = (V_{SP}-V_{TP})$ is plotted for different V_G. When V_G is made more negative keeping V_S constant, V_{SP} remains almost constant but the V_{TP} increases due to the background ions, which are accelerated by the negative grid bias voltage from the source plasma region. So as a result ΔV_{ST} decreases. From the Fig. 5 it is seen that ΔV_{ST} is higher for more positive value of V_S at a fixed value of V_G. When V_S is increased keeping V_G constant, source plasma potential increases accordingly and it floats few volts above the anode bias potential V_S and as a result most of the electrons are getting better trapped by the source region, *i.e.* the barrier for electrons (ΔV_{SG}) increases, but it increases the energy of the injected ion beam in the target region [11]. If keeping V_S at a more positive value, when V_G is further increased towards negative, the screening effect of the grid become more significant for the electrons, *i.e.* ΔV_{SG} is further increased. The combined effect of V_S and V_G makes the value of the target plasma potential close to the source plasma potential. In other words, we can say that electrons are getting repealed whereas back ground ions in the source regions are getting accelerated towards the target region.

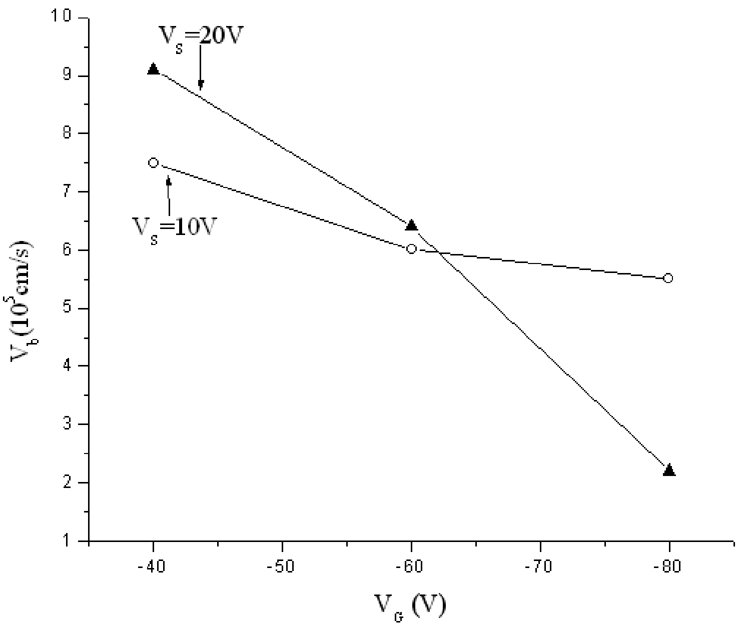

Fig. 7 – The variation of ΔV_{ST} $(=V_{SP}-V_{TP})$ with the negative V_G for fixed V_S= 10V and 20V.

The target plasma potential V_{TP} increases due to the increase in ion flow from the source region and V_{TP} is found to be higher at V_S= 20V than at V_S=10V.

Whenever the source plasma is at a higher potential than the target plasma in a DP device, an ion beam is produced which enters the target from the source plasma region due to the free fall of ions caused by the potential difference ΔV_{ST}. The energy of this free fall ion beam can be calculated from the relation [4, 5],

$$E_b = \tfrac{1}{2} M_i V_b^2 = e\, \Delta V_{ST} \tag{1}$$

where V_b is the beam velocity and M_i is the mass of the argon ion.

Fig. 7 shows that ΔV_{ST} decreases with the increase in V_G for both V_S=10V and 20V. This suggests that the ion beam energy E_b decreases with the increase in negative grid bias voltage. Taking the values of ΔV_{ST} for different values of V_G at V_S=10V and 20V, we can calculate the corresponding values of V_b from equation (1). The V_b is found to decrease with the increase in negative V_G. This is shown in Fig. 8. The value of V_b is higher than the ion acoustic velocity (C_S), which is in accordance with the Bohm criterion of sheath formation. The Bohm sheath criterion says that ions must enter the sheath region with a velocity greater than the acoustic velocity.

The sheath thickness (d) of the ion sheath formed at the separation grid can be calculated by substituting the values of different V_G and I_G in the well-known Child-Langmuir law,

$$I_G = (4/9)\, \varepsilon_0\, A\, (2e/M_i)^{1/2}\, V_G^{3/2}\, d^{-2} \tag{2}$$

In equation (2), ε_0 is the permittivity in free space, A is the surface area of the grid, e is the electronic charge, M_i is the ion mass and d is the sheath thickness. The sheath thickness d is found to increase with the increase in negative V_G. Sheath thickness d also depends indirectly on V_S, which controls I_G.. For a fixed value of V_G, when V_S is increased, contraction of the sheath takes place as the grid receive more ion flux due to the increase in source plasma potential V_{SP}.

At high ion density, the Debye length $\lambda_D\ (=\varepsilon_0 K T_e/n_0 e^2)^{1/2}$ is small and hence the sheath thickness. The variation of sheath thickness "d" with the change in negative grid bias voltage for V_S=10V and 20V are shown in Fig. 9.

From Fig. 8 and Fig. 9, we can say that V_b is inversely proportional to the sheath thickness d. When the negative grid bias voltage V_G is increased, more ions will be accumulated around it and as a result ion space charge layer will grow. This growing positive space charge layer in turn decelerate the ion beam moving from source to target region.

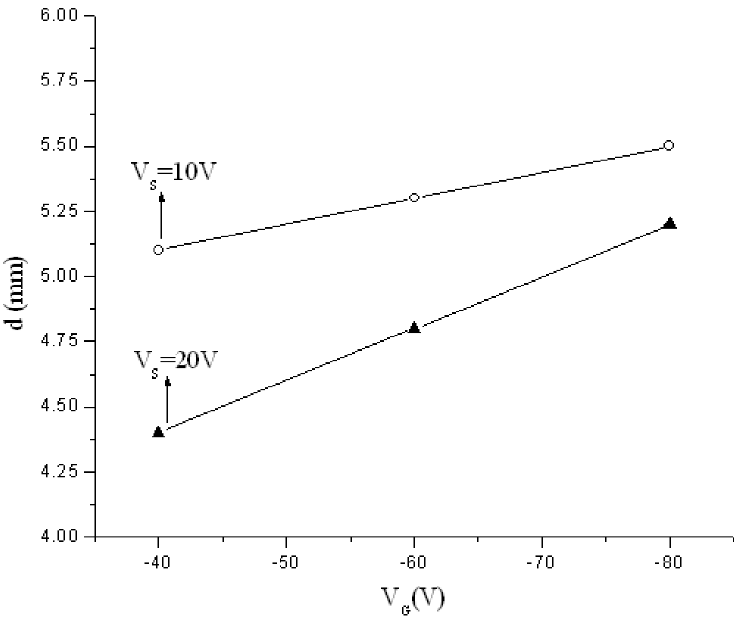

Fig. 8 – The variation of beam velocity V_b with different grid bias voltage V_G for fixed V_S=10V and 20V.

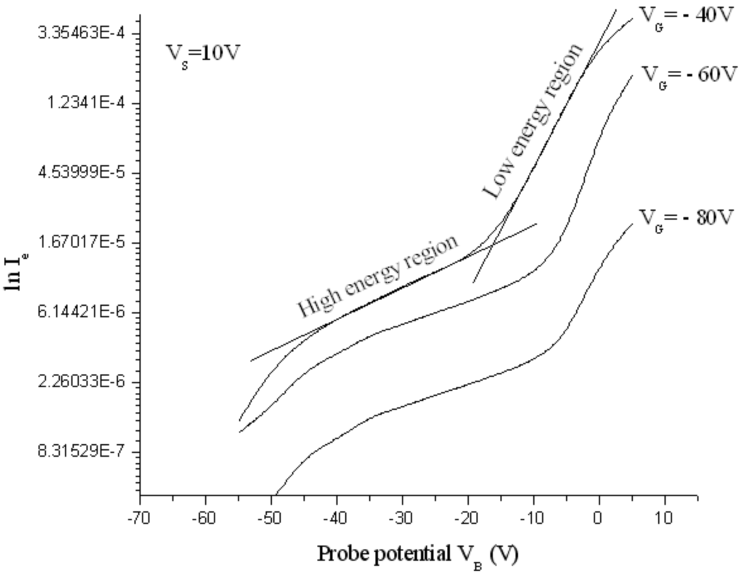

Fig. 9 – The variation of sheath thickness d with different grid bias voltage V_G for fixed V_S=10V and 20V.

4. CONCLUSIONS

The source plasma parameters are almost independent of negative grid bias voltage V_G. The target plasma density and potential are highly influenced by V_G. The plasma potential becomes more positive with a fall in density as the V_G is increased towards negative. For a particular value of grids bias voltage, target plasma potential is higher for more positive value source anode bias voltage.

When the source plasma is at a higher potential than the target plasma region, a free fall ion beam moves from source to target. When source plasma potential is further increased by increasing the V_S, the enhanced ion flux (beam ions) contributes to the grid current and hence grid current increases. The velocity of this ion beam depends on the V_S. Again, if V_G is increased keeping V_S fixed, the velocity of the beam is found to decrease, but at the same time grid current increases. The velocity or the energy of the ion beam gets reduced as a result of the increase in plasma potential in the target region. The sheath thickness and the beam velocity are found to be inversely proportional.

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