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Spatial Variation of Plasma Parameters in Argon Plasma from a Washer Stacked Plasma Gun

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Abstract: ***In this communication, spatial variation of ion density and electron temperature of argon, an inert gas, plasma are reported. Plasma is created by using a washer stacked plasma gun. The plasma structure is short lived (~ 1 ms). The square wave pulse fed to gun is only ~ 140µs. The measurements are done by using double probe. Ion density is found to be ~ 10^{17} $m^{-3}$and electron temperature is ~ 10^{3} – 10^{4} K for discharging potential 1 kV. It is observed that both ion density and electron temperature decreases as the distance from gun mouth is increased. Increasing applied voltage both ion density and electron temperature increases.***

Keywords: Ion density, electron temperature, plasma gun, double probe

1. Introduction

Plasma Science and Technology is an emerging field of research in recent days. Characterization of plasma parameters of various sources shall contribute immensely to the data base. Plasma gun is a very good source to produce short lived plasma structures and have a wide range of applications. Button-type gun [1], rail gun [2], occluded gas source [3], co-axial gun [4.5], supersonic plasma neutral source [6], hydrogen plasma gun[7], titanium hydride gun [8], washer gun [9-10] are different types of plasma guns used worldwide. Gun energized by pulse forming network (PFN) is a very good source to produce plasma structure of the desired density and temperature.

Since, plasma is basically an ensemble of charged particles, estimating parameters like number density, thermal velocity etc. of charged species usually give an idea about the behavior of plasma. Not only plasma parameters but also dynamics of plasma is expressed qualitatively as well as quantitatively using simple diagnostic tools, probes. Probe method is quite good technique to measure plasma parameters of a transient plasma structure [11-12].

In this work we have used double probe for measuring plasma parameters as it is easy to fabricate and use. The method of the floating double probe has two merits in a comparison with the single probe [13]. The probes are in a floating state having no relation to the electrodes of discharge. The amount of current flowing into the probe is so small that the probe measurement does not have any effect on the plasma because it does not exceed the saturation value of the positive ion current. The double probe method should be recognized especially in its application to changing plasma, namely, after glow, electrode less, pulse plasma and high frequency discharges. A double probe method has been developed which exerts a negligible influence on a discharge and which seems to yield accurate temperature data in all types of discharges including decaying plasma [11].

2. Experimental

The compact plasma system (CPS) is a table top device [14]. The plasma chamber is made up of SS-304 material with vacuum pump coupled with it. The thickness of the chamber is ~ 5 X 10^{-3} m. The system was hermetically sealed (basically no detectable leaks or leaks rate is zero). It was ensured that there were no serious leaks in the oil filled section of the oil pan in the rotary vane pump and virtual leaks from hollows and cavities inside cast parts, blind holes and joints of the plasma chamber at the time of commissioning. O'rings were placed between flange and window to ensure hermetically sealed system. Silicone vacuum grease was also used to avoid leaks in detachable connections whenever needed.

Transparent (acrylic) and SS flanges are designed to use as per need. Wilson feed through system is designed and tested which proved to be very useful for probe mounting inside the chamber making desired vacuum intact. A multi cathode and mono anode plasma gun is designed, fabricated, tested and mounted on the CPS device as a source of moving plasma. Anode is made up of copper whereas inter connected brass washers used as cathode are stacked between teflon sockets which are good insulators. The gas feed network injects desired gaseous substance into gun body to make it operational. An electromagnetic valve is used to inject gas into the gun from cathode side. In these experiments inert gas, argon is used as the working gas. The gun is energized by a multistage Guillemin E-type pulse forming network (PFN), which produces square wave pulse [15].

Double probe is used to estimate ion density and electron temperature. The probe is made up of tungsten (99.99% pure). The probe material is connected with copper wire by the method of point brazing. Ceramic base is used as probe holder. Care was taken so that electrical noise from supply line don't interfere double probe circuit. The probe is inserted into the CPS device through Wilson Feed Through system. The schematic diagram of plasma gun and allied circuit is shown in figure 1 and the double probe biasing scheme is shown in figure 2.

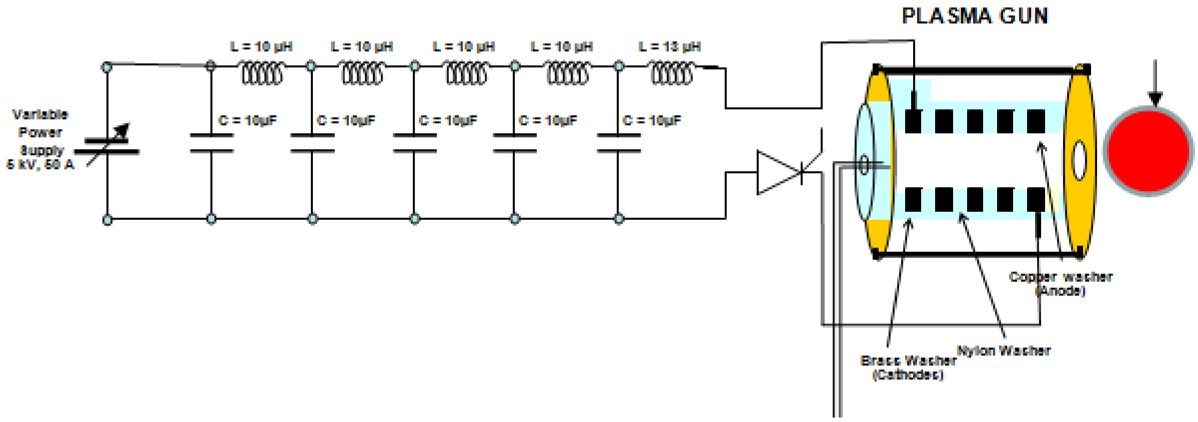

Figure 1: Schematic diagram of plasma gun and allied circuit

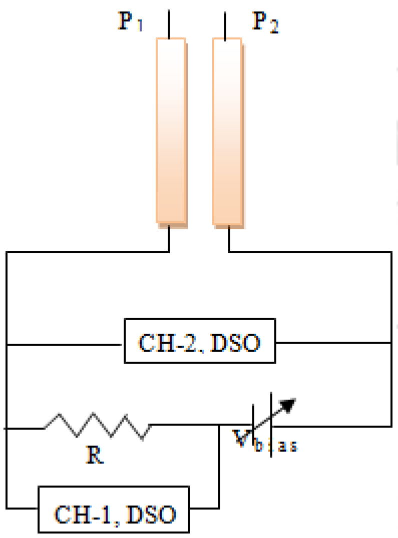

Figure 2: Schematic diagram of double probe circuit

3. Theory

The ion density and electron temperature of the gun discharge plasma are estimated using a double probe [11-13]. When two identical probes immersed in the plasma, current I_s will flow through the external circuit on application of the potential difference V_a between the probes. The graph between the potential and current is called of plasma. I ~ V characteristic curve is symmetrical in nature. When no current is drawn i.e. the probe is floating

$$i_{+1} + i_{+2} = -(i_1 + i_2) \tag{1}$$

where i_{+1} and i_{+2} are the ion currents and i_1, i_2 are the electron currents to probes 1 and 2 respectively.

When V_a is increased, a point is reached where the second probe 2 is so negative that no electron can reach the probe. So, equation 1 becomes

$$i_{+1} + i_{+2} = -i_1 \tag{2}$$

It is worth noting that, i_{+2} will not increase even if V_a is increased further and attains a saturation value for an ideal case when $r_p/\lambda_D \rightarrow \infty$. This current is called ion saturation current. In ideal case electron energy distribution is assumed to be Maxwellian; hence the electron current to the probe is given by

$$i_1 = i_{01} A_{p1} \exp\left(\frac{eV_1}{kT}\right), V_1 \langle 0 \tag{3}$$

$$i_2 = i_{02} A_{p2} \exp\left(\frac{eV_2}{kT}\right), V_2 \langle 0 \tag{4}$$

where i_{01} and i_{02} are random electron current densities. Using equation-3 and 4 in equation-1 one can write

$$i_{+1} + i_{+2} = i_{01} A_{p1} \exp\left(\frac{eV_1}{kT}\right) + i_{02} A_{p2} \exp\left(\frac{eV_2}{kT}\right) \tag{5}$$

Where

$$V_1 - V_2 = V_a - V_{bc} \tag{6}$$

$$i_{+1} + i_{+2} = -i_{01} A_{p1} \exp\left(\frac{eV_1}{kT}\right)\left[1 + \frac{i_{02} A_{p2}}{i_{01} A_{p1}} \exp\left(\frac{V_{bc} - V_a}{kT}\right) e\right]$$

In actual practice it is rarely achieved. Hence, equation-2 is modified and can be written as

$$\frac{dI_s}{dV_a} = \frac{dI_1}{dV_a} = -\frac{dI_2}{dV_a} \tag{7}$$

Using equation-3 and 4 in equation-5 and differentiating it equation-5 becomes

$$i_{01} A_{p1} \exp\left(\frac{eV_1}{kT}\right) \cdot \frac{e}{kT} \frac{dV_1}{dV_a} + i_{02} A_{p2} \exp\left(\frac{eV_2}{kT}\right) \cdot \frac{e}{kT} \frac{dV_2}{dV_a} = 0$$

$$i_1 \frac{dV_1}{dV_a} + i_2 \frac{dV_2}{dV_a} = 0 \tag{8}$$

Equation-6 can be written as

$$1 = \frac{dV_1}{dV_a} - \frac{dV_2}{dV_a} \tag{9}$$

When I_s=0 i.e. ion current is equal to electron current

$$i_{+1} = i_1 \exp\left(\frac{eV_1}{kT}\right) \text{and } i_{+1} = i_2 \exp\left(\frac{eV_2}{kT}\right) \tag{10}$$

Using equation- 9 and 10 in equation-8, one can write

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$$i_{+1}\frac{dV_1}{dV_a}+i_{+2}\left(\frac{dV_1}{dV_a}-1\right)=0$$

Or

$$\frac{dV_1}{dV_a}=\frac{i_{+2}}{i_{+1}+i_{+2}} \tag{11}$$

$$\frac{dI_s}{dV_a}=\frac{d}{dV_a}\left[A_{p1}i_{01}\exp\left(\frac{eV_1}{kT}\right)\right]$$

$$A_{p1}i_{01}\exp\left(\frac{eV_1}{kT}\right).\frac{e}{kT}.\frac{dV_1}{dV_a}=i_{+1}.\frac{e}{kT}.\frac{dV_1}{dV_a} \tag{12}$$

Using equation-11 in 12 one may write

$$\left[\frac{dI_s}{dV_a}\right]_{i_s\to 0}=i_{+1}.\frac{e}{kT}.\frac{i_{+2}}{i_{+2}+i_{+1}} \tag{13}$$

By drawing a graph between I_s and V_a the slope

$$\left[\frac{dI_s}{dV_a}\right]_{i_s\to 0}$$ at $i_s \longrightarrow 0$ will give electron temperature

$$T_e=\frac{i_{+1}\times i_{+2}}{i_{+1}+i_{+2}}\left(\frac{e}{k}\right)\times\frac{1}{slope} \tag{14}$$

Slope = $\left[\frac{dI_s}{dV_a}\right]_{i_s\to 0}$

The density of plasma can be calculated at either position of the probe using the equation

$$i_{+1}=\frac{1}{2}n_+.A_p.\left(\frac{e^3}{m_+}\right)^{\frac{1}{2}}.\left(\frac{kT}{e}\right)^{\frac{1}{2}}$$

Ion density

$$n_+=\frac{2m_+^{\frac{1}{2}}i_+}{e^{\frac{3}{2}}A_p}\left(\frac{e}{kT}\right)^{\frac{1}{2}} \tag{15}$$

Where m_+, A_p, e are the mass of ions, the area of the probe, charge and mass of the electron respectively.

4. Results and Discussion

In view of the symmetry of the system with respect to plasma, the respective roles of the two probes can be reversed by changing the polarity of the probes. The voltage current characteristics at base pressure 0.1 mb at discharging potential 1 kV at a distance 0.04 m from plasma gun is shown in Figure 3. In I ~ V characteristic curve, regions AB and CD are ion collection regions whereas in BC region both electrons and ions are collected by probe. Since electrons are collected in the region of BC, the corresponding electron temperature is calculated using equation-14 [11-12]. The electron temperature is found to be 17632 K. Using equation-15, the ion density is estimated to be 4.167 X $10^{17}m^{-3}$.

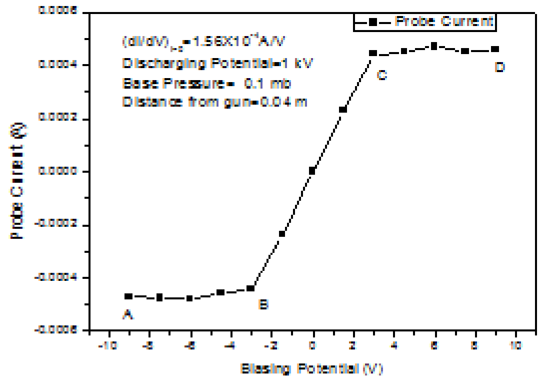

Figure 3: Variation of probe current with biasing potential (I ~ V characteristic curve)

From I~V characteristic curve the electron temperature and of plasma is estimated. The spatial variation of electron temperature for different base pressure is shown in figure 4.

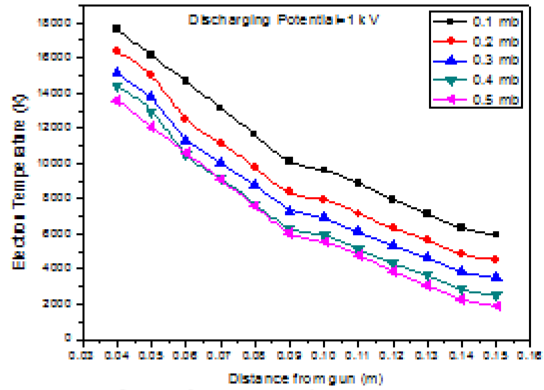

Figure 4: Spatial variation of electron temperature for different base pressure

It is observed from figure 4 that electron temperature decreases with increase in radial distance from gun mouth. The trend is similar for base pressure values 0.1 mb, 0.2 mb, 0.3 mb, 0.4 mb and 0.5 mb. It is evident that the nature of variation is almost similar at all pressure values reported here. Once the power is dumped into the gun, there is no external source which continuously feed energy to gun. Electrons lose energy by collision. So, the thermal speed of electrons in bulk plasma decreases, which is evident from the decreasing trend of electron temperature. When base pressure increases electron temperature decreases as the plasma becomes more collisional. The spatial variation of ion density of argon plasma for different base pressure is shown in figure 5.

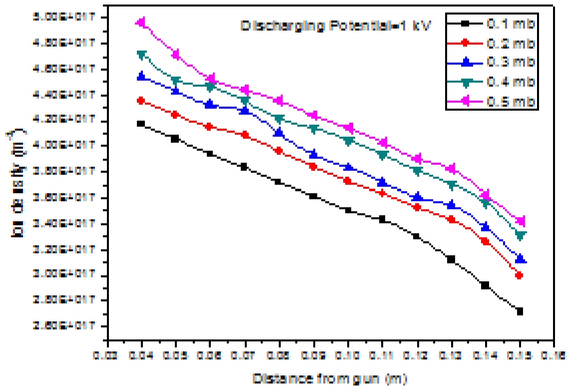

Figure 5: Spatial variation of ion density for different base pressure

It is observed from figure 5 that ion density decreases with increase in radial distance from gun mouth. The trend is similar for different base pressure values. As base pressure increases, neutral density increases, which resulted in increase in ion density. The spatial variation of electron temperature and ion density of argon plasma for different base pressure is shown in figures 6 and 7 respectively for different discharging potential.

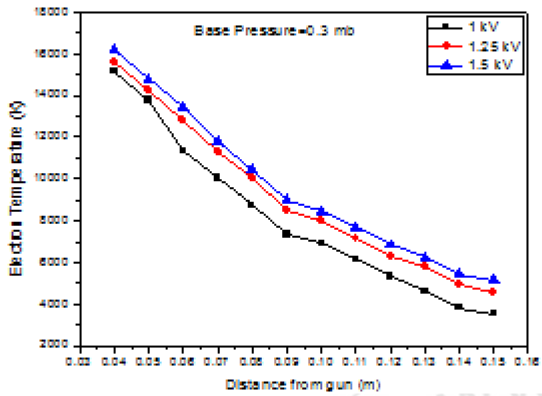

Figure 6: Spatial variation of electron temperature for different discharging potential

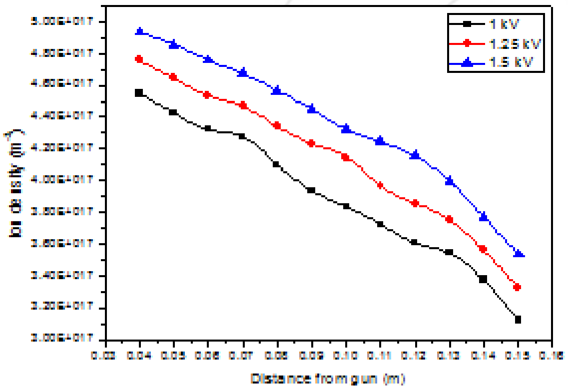

Figure 7: Spatial variation of electron temperature for different discharging potential

It is observed from figure 6 and 7 that electron temperature as well as ion density increases with increase in discharging potential. By increasing discharging potential, more energy is fed to the plasma gun. This resulted in more ionization and increase in electron temperature and ion density.

5. Conclusion

Spatial variation of ion density and electron temperature are estimated using double probe. The ion density is ~ 4.167 X $10^{17}m^{-3}$. Electron temperature is ~ 1 eV. The ion density and electron temperature decrease as the distance from gun mouth increases. When base pressure increases electron temperature decreases as the plasma becomes more collisional. As base pressure increases, neutral density increases, which resulted in increase in ion density. More the discharging potential, more ionization is taking place increasing the ion density. As discharging potential increases the electrons in plasma accumulates more thermal energy, which is evident from increase in electron temperature.

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