



DIAGNOSTICS OF LOW PRESSURE DC GLOW DISCHARGE USING DOUBLE LANGMUIR PROBE

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ABSTRACT

This paper reports the result of electrical diagnostics of low pressure DC glow discharge using Langmuir double probe. The electron and ion distribution function at the probe sheath edges are considered to be Maxwellian so that the most important requirement of pre-sheath and sheath transitions are satisfied. The electrons and ions are assumed to penetrate the sheath region due to their large thermal velocities. Using the probe biasing technique, the discharge plasma parameters like electron temperature (KT_e) and electron number density (n_e) are measured at the applied voltage ranging from 400V to 700V, between the two electrodes, and pressure, inside the discharge tube, ranging from 0.013mbar to 0.070mbar. Our result showed that electron temperature (KT_e) and electron number density (n_e) increases with the pressure inside the discharge tube and applied voltage across the electrodes.

Keywords: Cold Plasma, Diagnostics, Glow Discharge, Electron Temperature, Double Probe

INTRODUCTION

In order to understand the property of newly identified plasma, it is necessary to have knowledge of some quantities which describe the state of plasma. The phenomenon of measurement of such quantities is known as plasma diagnostics [1]. Low pressure plasma science has been established as the major research field at present world. This type of plasma is non-equilibrium plasma where the electron temperature is much higher than the ion temperature [2].

In recent years, several efforts have been made in the field of low pressure cold plasma researches due to its wide applications in industry, environment and medicine such as radiation processing [3], surface treatment [4], biomedical science [5], pollution control [6], gas lasers [7], light source [8], chemical synthesis [9] and MHD energy converters [10]. One of the most important commercial applications of low temperature glow discharges is the fabrication of microelectronic circuitry [11].

Before the application of cold plasma to the desired purposes, it is necessary to perform some diagnostics technique to characterize and control its parameters. So plasma diagnostics is very important in plasma research as well as other industrial and environmental applications [12]. For this purpose, it is appropriate to use the double Langmuir probe, developed by Irving Langmuir



and his co-worker in 1920's, which is a kind of collecting probe having two metallic tips relatively biased to each other [13]. Like double probe, Single and Triple probes are also used for diagnostics purposes. However, single probe perturbs the state of plasma and Triple probe is an elegant electronic configuration specially used for the diagnostics of rapidly changing plasma such as low frequency plasma and plasma shock waves [14, 15]. In this paper, use of double Langmuir probe for the diagnosis of low pressure DC glow discharge has been discussed.

DERIVATION OF PLASMA PARAMETERS

Determination of Electron Temperature (KT_e)

Double probe system has two electrodes of equal surface area and is immersed in the plasma. One of the probes draws current I_1 while the other draws current I_2 . To find electron temperature, the probes must be operated at floating potential V_f of the plasma. This means, the applied probe potential and plasma potential must be equal.

$$I_1 = I_{1is} - I_{1es} \exp \left[\frac{e(V_1 + V_f - V_s)}{KT_e} \right] \quad (1)$$

Where, I_{1is} is the ion saturation current, I_{1es} is the electron saturation current due to probe 1 and V_s is the probe sheath potential.

Using definition of floating potential,

$$I_{es} \exp \left[\frac{e(V_f - V_s)}{KT_e} \right] = I_{sat} \quad (2)$$

Where I_{sat} is the resultant ion saturation current of the two probes.

Hence, I_1 can be written as,

$$I_1 = I_{1is} \left[1 - \exp \left(\frac{eV_1}{KT_e} \right) \right] \quad (3)$$

Similarly,

$$I_2 = I_{2is} \left[1 - \exp \left(\frac{eV_2}{KT_e} \right) \right] \quad (4)$$

If probe area is equal, then it implies,

$$I_{1is} = I_{2is} = I_{sat} \quad (5)$$

Also zero net probe circuit current leads to the definition:

$$I \equiv I_1 = -I_2 \quad (6)$$

Combining, (3), (4), (5), and (6) we get,

$$\frac{I - I_{sat}}{-I - I_{sat}} = \exp \left(\frac{e\Psi}{KT_e - e} \right) \quad (7)$$

where, $\Psi = V_1 - V_2$ is the difference in potential of the two probes.

Differentiating (7) with respect to Ψ at $\Psi = 0$ yields,

$$\left[\frac{dI}{d\Psi} \right]_{\Psi=0} = -I_{sat} \operatorname{sech}^2 \left[\frac{e\Psi}{2KT_e} \right]_{\Psi=0} \left(\frac{e}{2KT_e} \right) \quad (8)$$

Therefore, the electron temperature is related to the slope of double probe characteristics by:

$$\left[\frac{dI}{d\Psi} \right]_{\Psi=0} = -I_{sat} \left(\frac{e}{2KT_e - e} \right) \quad (9)$$

Hence,

$$KT_e = -\frac{I_{sat} e}{2 \tan \theta} \quad (10)$$

Where, negative sign indicates the charge of electron.

**Determination of Electron Number Density (n_e)**

The Planar Sheath Equation can be derived from ion equation of continuity and its solution provides Bohm's Sheath Criteria as,

$$u_0 \geq \left(\frac{KT_e}{M}\right)^{\frac{1}{2}}$$

This inequality shows that ions can reach the probe surface only if they have velocity at least equal to acoustic velocity [16]. If the probe has surface area A and ions entering the sheath have a drift velocity u_0 then ion current collected can be written as,

$$I_{sat} = n_s e A \left(\frac{KT_e}{M}\right)^{\frac{1}{2}} \quad (11)$$

The density n_s is plasma density at the edge of the sheath. Let us define sheath edge in such a way that u_0 is exactly equal to ion acoustic velocity $\left(\frac{KT_e}{M}\right)^{\frac{1}{2}}$. To accelerate ion to this velocity requires a potential called pre-sheath potential given by $|\Phi| \geq \frac{\frac{1}{2}KT_e}{e}$, so that the sheath edge has the potential, $\Phi_s = -\frac{\frac{1}{2}KT_e}{e}$ relative to the body of plasma. If electrons are Maxwellian, this determines n_s as

$$n_s = n_e e^{\frac{e\Phi_s}{KT_e}}$$

or,

$$n_s = n_e e^{\frac{-\frac{1}{2}KT_e}{KT_e}}$$

or,

$$n_s = n_e e^{-\frac{1}{2}}$$

So,

$$n_s = 0.61n_e \quad (12)$$

Using (12) in (11) we get,

$$I_{sat} = 0.61n_e e A \left(\frac{KT_e}{M}\right)^{\frac{1}{2}} \quad (13)$$

EXPERIMENTAL DESCRIPTIONS

Figure (3.1) shows the schematic diagram of double Langmuir probe system used in this study. A high voltage up to 1000V was used from DC source to generate plasma inside the low pressure discharge tube. In order to achieve the required low pressure, a rotary pump was used. The plasma was produced in a discharge tube, made up of glass material, of thickness 6mm with external diameter 17cm and length 33cm. Probe power supply was automatically adjusted in the apparatus. The output of the probe power supply was measured by oscilloscope. The applied probe voltage (v_p) and output probe current (i_p) are simultaneously measured and analyzed. For this purpose, the probe needle made up of Nickel-Chrome with length 6×10^{-3} m and diameter 0.5×10^{-3} m was used. The necessary insulation around the probe needle was done using glass materials. In order to generate glow discharge inside the tube, DC power supply ranging from +40V to -40V was applied and distance between two electrodes (each of diameter 10 cm) was adjusted to be 10cm.

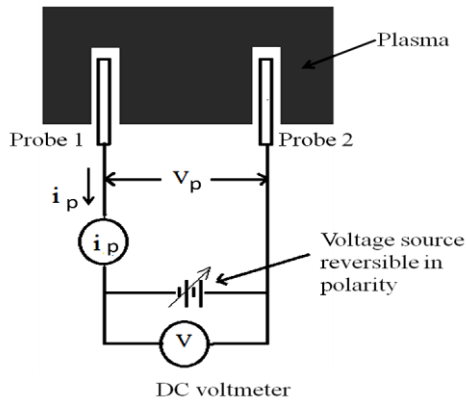


Figure 3.1: Schematic Diagram for Double Probe System

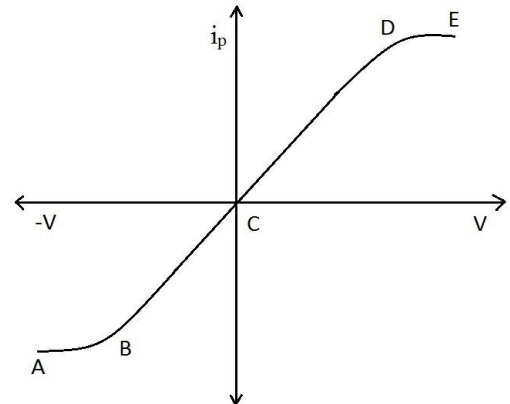


Figure 3.2: Characteristic Curve for Langmuir Double Probe

Experimentally, we obtain symmetric curve when the area of both probe are equal. This is because plasma properties are same in the vicinity of both the probes. In the above I-V curve, AB and/ or DE represent saturation region. Ideally current in this region is independent of the potential difference applied. However, the sheath area expands as the applied potential difference increases and so the collected current also increases steadily in real practice.

When probe 1 is highly negative, the ions are collected from plasma around the probe surface and we get ion saturation current as shown by the portion AB of the plot. At the same time, probe 2 is feebly positively biased drawing small electron current. However, algebraic sum of ion and electron current gives the resultant probe current of the two identical probes. Moreover, when probe 1 is made less negatively biased not only ions but also small amount of electrons are collected around the probe sheath region. The probe current obtained in this case is represented by portion BC of the curve. At point C, no current is drawn by the probe, probe potential in two probes are same and is equal to the plasma potential called **Floating Potential**. When the direction is reversed, probe 2 becomes negative and the curve CDE is obtained exactly as before.

RESULTS AND DISCUSSION

The electron temperature and electron number density can be found by the I-V curve of probe current and probe potential. The I-V characteristics of double Langmuir probe method operated at 400V and pressure 0.013mbar is shown in Figure (4.1). From the Figure (4.1), slope at origin is 2.72933×10^{-7} and ion saturation current (I_{sat}) is 3.09×10^{-6} A. Using the values of probe diameter and length, the probe surface area exposed to experimental plasma is 9.61×10^{-6} m². Mass of ion obtained by air discharge is taken to be 5.6×10^{-26} Kg.

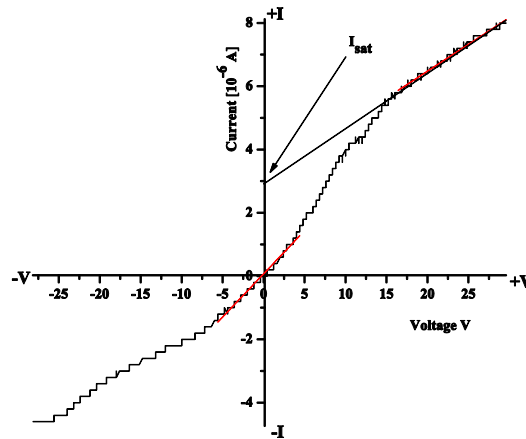
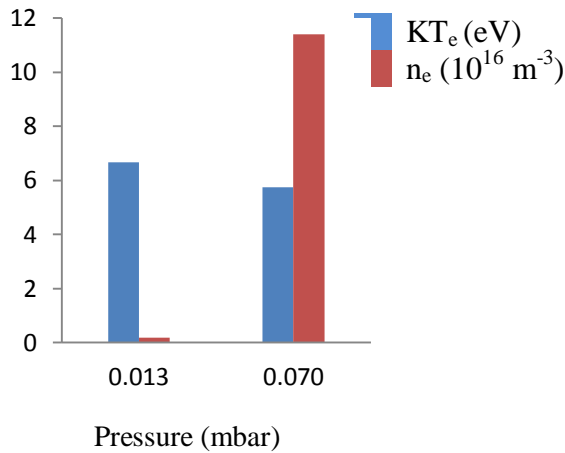


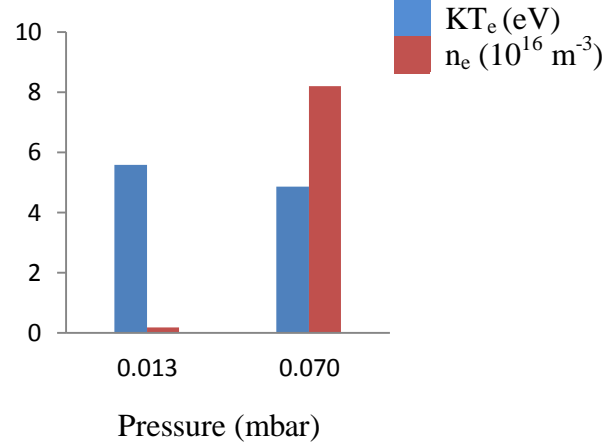
Figure 4.1: I-V Curve of double Langmuir probe for voltage 400V and pressure 0.013mbar
 Now using equation (10), value of electron temperature is 5.65eV. Using this value in equation (13), electron number density is found to be $0.84 \times 10^{15} \text{ m}^{-3}$. Similarly, calculations of electron temperature and electron density for different values of voltage and pressure have been done and listed in Table 4.2

Voltage (V)	Pressure (mbar)	Electron Temperature KT_e (eV)	Electron Density (n_e)
600	0.013	6.68	$1.82 \times 10^{15} \text{ m}^{-3}$
600	0.070	5.74	$1.14 \times 10^{17} \text{ m}^{-3}$
550	0.013	5.59	$1.92 \times 10^{15} \text{ m}^{-3}$
550	0.070	4.87	$0.82 \times 10^{17} \text{ m}^{-3}$
650	0.013	5.41	$1.25 \times 10^{16} \text{ m}^{-3}$
700	0.013	6.10	$1.23 \times 10^{16} \text{ m}^{-3}$
400	0.013	5.65	$0.84 \times 10^{15} \text{ m}^{-3}$
450	0.070	8.46	$0.038 \times 10^{17} \text{ m}^{-3}$

The various values of electron temperature and electron density at different values of applied pressure and voltage are presented by the bar graphs below. For the better understanding of the results, comparison of electron temperature (KT_e) and electron density (n_e) has been made by making suitable adjustment in the value of pressure and voltage in discharge tube. This comparison for the value of electron temperature (KT_e) and electron number density (n_e) has been done in three different phases; Bar Graph (4.3) and Bar Graph (4.4) shows the case in which voltage is constant and pressure is changed, Bar Graph (4.5) shows the result for constant pressure with voltage varied and finally in Bar Graph (4.6) both voltage and pressure has been changed.

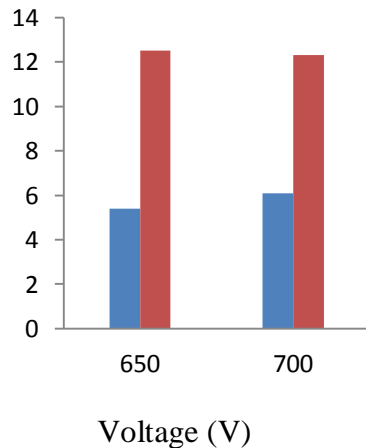


Graph (4.3): Variation of electron temperature and density at constant applied voltage 600V

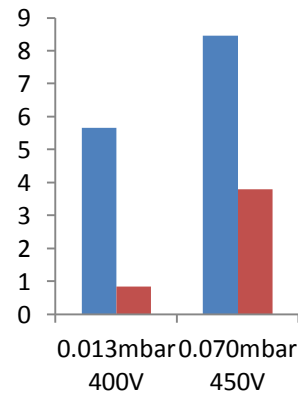


Graph (4.4): Variation of electron temperature and density at constant applied voltage 550V

In Graph (4.3) and Graph (4.4), voltage is kept constant at 600V and 550V respectively with pressure increased from 0.013mbar to 0.070mbar. The graphs clearly show the increase in the value of electron number density with corresponding increment of pressure inside discharge tube whereas the electron temperature seems almost same within the same voltage range. As pressure increases, the number of neutral atoms inside DC discharge tube increases and so the highly energetic electrons emerging out from cathode get sufficient neutral atoms to ionize in their medium resulting an increase in electron number density.



Graph (4.5): Variation of electron temperature and density at constant pressure 0.013mbar



Graph (4.6): Variation of electron temperature and density at varying pressure and voltage

In Graph (4.5), pressure is kept constant at 0.013mbar and the voltage is increased from 650V to 700V. At constant pressure, electron number density seems to remain unchanged while the



electron temperature has increased as the applied voltage has increased. This is due to the fact that increase in the value of applied voltage increases the thermal motion of the electrons and ions in plasma. Therefore, electrons and ions get sufficient energy to overcome sheath barrier around the probe and large amount of electrons and ions get collected in the probe surface which increases the value of electron temperature.

The Graph (4.6) shows that the value of electron temperature and electron number density both increases with corresponding increase in voltage and pressure inside the discharge tube. As far as the electron number density is concerned, although it reciprocally depends upon the electron temperature as mentioned in the probe theory but in our case, this increase in electron number density might be due to an increase in ionization events in the discharge plasma at higher pressure. An increase in voltage, along with increase in pressure, can play a dual role of increasing electron temperature—by producing highly energetic electrons from cathode, as well as increase in electron density by ionizing more number of neutral atoms and molecules present inside the discharge tube. However, with the increase of gas pressure, electron mean free path becomes short which results an increase in electronic inelastic collision and so the electron energy decreases.

CONCLUSIONS

This study has showed the change in the value of electron temperature and electron number density according to the corresponding change in applied voltage and pressure inside the discharge tube. Experiments were performed in the pressure range from 0.013mbar to 0.070 mbar and voltage range from 400 V to 700 V. In this range of pressure and voltage, the electron temperature has been found in the range from 4.87eV to 9.96eV and electron number density is in the range from $0.84 \times 10^{15} \text{ m}^{-3}$ to $1.14 \times 10^{17} \text{ m}^{-3}$. At constant pressure inside discharge tube, it has been seen that electron temperature increases with increase in applied voltage. On the other hand, at constant voltage inside the discharge tube, it is seen that electron number density increases with increase in applied pressure.

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