International Journal of Recent Research and Review, Vol. VII, Issue 2, June 2014
ISSN 2277 – 8322

Influence of Discharge Voltage and Pressure on the Plasma Parameters in a Low Pressure DC Glow Discharge

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***Abstract* - Langmuir double probe is a very useful diagnostics for studying the plasma parameters at low pressure discharge and this paper reports the measurement of electron temperature (T_e), ion saturation current (I_{sat}) and electron density (n_e) in a low pressure DC glow discharge in air using *I-V* characteristics of double probe and the objective of the study is to investigate the effect of pressure and applied voltage on the plasma parameters in the discharge. In addition, Debye length (λ_D), plasma frequency (f_{pe}), floating potential (V_f) have also been calculated and their dependance on the applied voltage and working pressure have been studied. Measurements show that (T_e), (λ_D) and (V_f) gradually decrease on increasing the applied voltage or working pressure, but (I_{sat}), (n_e), and (f_{pe}) increases on increasing the applied voltage and working pressure. The maximum values of these parameters are obtained at 0.5 mbar pressure.**
***Keywords* - Langmuir probe, Electron temperature, Plasma density, Plasma frequency, Debye length**

I. INTRODUCTION

The DC glow discharges have been extensively used in the gas laser, material processing [1] and thin film deposition [2]. Before applying the discharge for any purpose, it is necessary to determine the basic discharge parameters like electron temperature and plasma density and to understand their dependence on the discharge parameters such as discharge voltage and operating gas pressure. Various methods, such as emission or absorption optical spectroscopy, microwave interference, mass spectroscopy and Langmuir probe have been used to diagnose the plasma. In particular, the Langmuir double probe, introduced by Johnson and Malter at 1950, is one of the most powerful and experimentally simple technique for plasma characterization over a wide range of plasma densities. [3,4] It is best suited for localized parameter measurement of the plasma because it collects very little amount of electron current without disturbing the plasma condition. [5] Another advantage using double probe is that it can be used for time varying and electrodeless discharges as both probes are maintained at floating conditioin. Almost all the other techniques mentioned above give information averaged over a large volume of plasma. [6] The limitation of the method is that it cannot sample the entire electron distribution but are limited to collect electrons from the high energy tail of the distribution [7] because only fast moving electrons are able to overcome the retarding potential in the plasma sheath of the probe to reach the probe.

In the double probe system the two probes are biased in such a way that the probe potentials are always lower than that of the plasma potential and the entire system is allowed to float so that the net current which is the algebric sum of both electron current and ion current to each probe is zero. [5] When both probes have the same potential with respect to the plasma potential, each probe draws equal amount of ions and electrons. But when one probe is more negatively biased, it draws more ions than electrons while at the same time the other probe collects more electrons than ions. The excess electrons pass through the external circuit and give rise to the probe current. On the other hand, when one probe is biased sufficiently negative relative to the plasma, it collects only positive ions and reaches the saturation condition and repels all electrons while the other probe only attracts electron current to neutralize the ion current so that the system is again in floating condition. In the present work we have measured the various plasma parameters like electron temperature, ion saturation current, electron density, plasma frequency, and Debye length and also studied their variation with pressure and applied voltage using Langmuir double probe at low pressure DC glow discharge.

II. EXPERIMENTAL SETUP AND METHODOLOGY

The photograph of the plasma reactor used for the characterization of the low pressure dc glow discharge in air is shown in fig.1. It is made of thick glass cylinder of length 34 cm long and external diameter of 16.5 cm. The vacuum is created inside the plasma reactor at the desire pressure range (0.07 mbar - 0.75 mbar) with the help of a rotary pump and the pressure is controlled by using a needle valve and is measured by using a pirani gauge. The discharge is produced inside the chamber in between two circular electrodes made of stainless steel of diameter 10 cm separated at the distance of 8 cm and the maximum voltage that can be applied across it is 1 kV. The two identical cylindrical electrostatics probes each with radius 0.5 mm and length 6 mm made of tungsten are inserted inside the positive column of the discharge region. The double probe is connected to a power supply capable of biasing it at various potentials (positive or negative) relative to plasma and the current collected by the probe provides information on the conditions of the plasma. The system that we used to calculate the plasma parameters is automated and the probe characteristic is acquired digitally by employing a digital voltage sweep of $\pm$ 50 V over 2500 points. The probe current is taken across a 10 kΩ current sensing resistor so that a maximum 500 μA current can be drawn by the probe. Both probe current and probe voltage are recorded digitally by using Tektronix TDS 2014C oscilloscope. The data obtained can be transferred to a personal computer for further analyses.

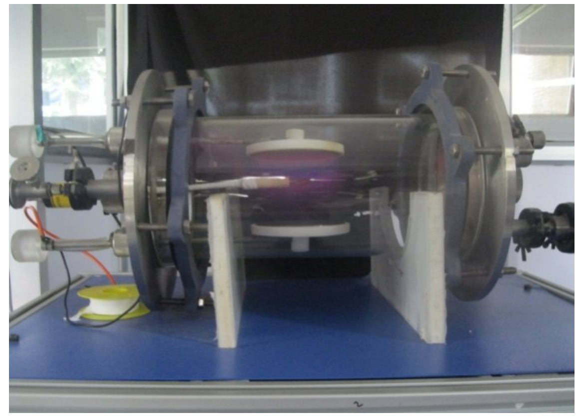

Fig.1 Photograph of low temperature plasma reactor with langmuir double probe.

During the experiment, it is assumed that the plasma obeys Maxwellian distribution so that the electron temperature and electron density can be determined from the I-V characteristics of the probe.

The electron temperature (T_e) is determined by the relation:

$$T_e = \frac{I_{sat}}{2 \times \ slope\ at\ origin} \dots\dots\dots\dots\dots\dots (1)$$

While the electron density can be determined from the ion saturation current and electron temperature using the following equation: [8, 9]

$$I_{sat} = 0.6eAn_e\sqrt{\frac{KT_e}{m_i}} \dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

The factor 0.6 is due to the reduction of the ion density in the presheath region over which the ions are accelerated up to the Bohm velocity. [9]

The Debye length (λ_D) which gives the thickness of the sheath or shielding distance of electric field at the probe tip and the plasma frequency (f_{pe}) can be determined using following equations:

$$\lambda_D = \sqrt{\frac{\varepsilon_0 KT_e}{ne^2}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

$$f_{pe} = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

The floating potential is another important parameter which determines the condition at which the net ion flux to the probe is equal to the electron flux. In the double probe system it is always measured with respect to the plasma potential and can be obtained by the relation given below [5]:

$$V_f = \frac{KT_e}{2e} \ln\left(\frac{mT_e}{MT_i}\right) \dots\dots\dots\dots\dots\dots\dots (5)$$

III. RESULTS AND DISCUSSION

In the double probe system, the electron temperature and ion saturation current are obtained by drawing a tangent at zero relative biased voltage (V_d) and at ion saturation region as shown in the fig.(2) using equation (1) and these values were used to calculate the electron density and other parameters.

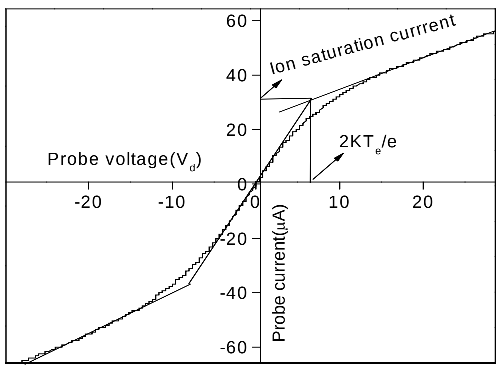

Fig.2 Current-voltage characteristics of double probe

The dependence of electron temperature (T_e) at different applied voltage and operating pressure is shown in fig. 3a and fig. 3b. It is observed that with the increased of input voltage from 800 V to 980 V at different fixed pressures from 0.07 mbar to 0.2 mbar, electron temperature decreases at slower rate. Similar trend in electron temperature is also observed with increased in pressure from 0.07 mbar to 0.75 mbar at fixed discharge voltage of 980 V at higher rate and this decrease in electron temperature may be due to increase in electron collision frequency with plasma species.

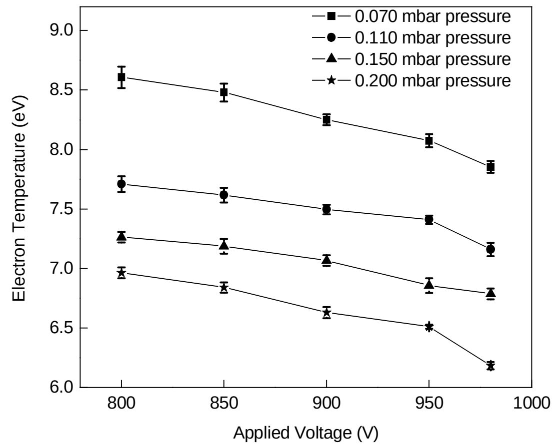

Fig.3a Dependence of electron temperature on applied voltage at different working pressure

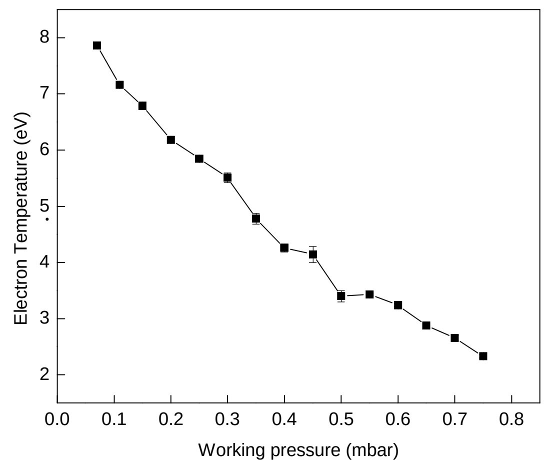

Fig.3b Electron temperature as a function of pressure at constant applied voltage 980V

On increasing the applied voltage or pressure, instead of gaining energy by the electron from the electric field, more and more energy is transferred from electron to plasma species during inelastic collision. This results in the decrease of the electron temperature. The current collected by the probe obviously depends on the density of the charge carriers in the plasma, the distribution of their velocity, its shape as well as its size. Fig. 4 shows the increase in ion saturation current on increasing the applied voltage at different fixed pressure. The increase in the ion saturation current on increasing the applied voltage and pressure is due to the increase in ionization events inside the plasma and decrease in ion saturation current beyond the certain limit of pressure may be due to the reduction in generation of charged particles or other charged particles loss mechanisms. The variation trend of the ion saturation current with pressure at fixed voltage 980V is shown in fig.5b.

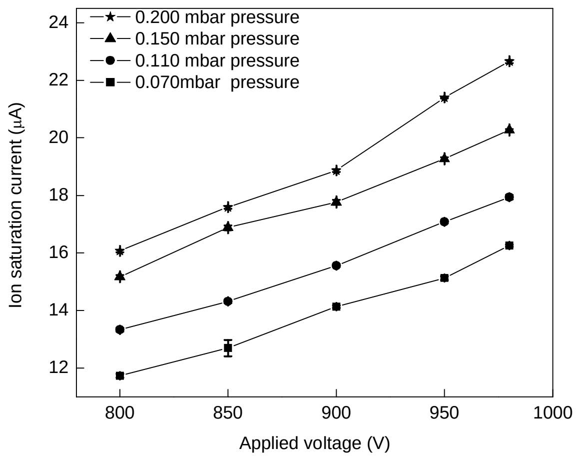

Fig.4 Ion saturation current as a function of applied voltage at different pressure

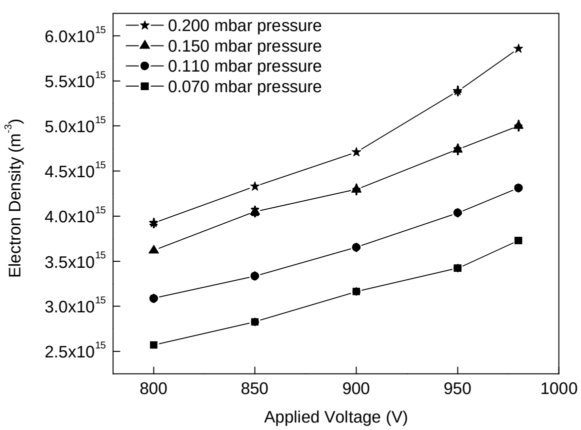

Fig.5a Variation of ion saturation current with applied voltage at different gas pressure

It is obvious from eq. (2) that there is inverse relation between electron temperature and electron density so decrease in electron temperature means to increase the electron density. Again electron density has direct relation with ion saturation current and ion saturation current increases on increasing the voltage due to the increase in the ionization rate by collisional effect inside the discharge region. As a result electron density increases at low gas pressure. The dependence of electron density on the applied voltage is shown in fig. 5a. Similarly, variation of electron density with gas pressure at constant potential of 980V is shown in fig. 5b along with variation of ion saturation current.

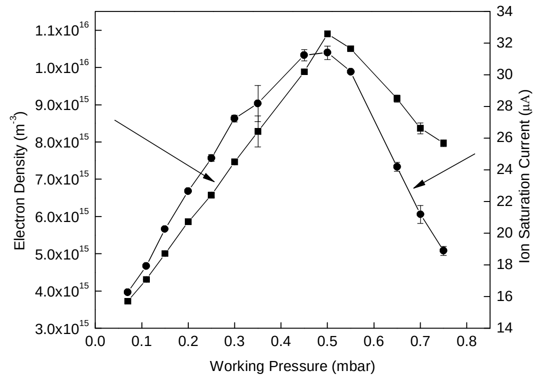

Fig.5b The variation of electron density and ion saturation current at different working pressure at constant voltage 980V

There is always generation as well as losses of the charge particles in plasma. Generation of charged particles is mostly due to the ionization as a result of inelastic collision while losses of the charged particles may be due to diffusion and volume recombination. Increasing and decreasing trends of the electron density with an increase in pressure is related to the transition of the dominant loss mechanism of the charged particles in the discharge region. At low pressure the dominant charged particle loss mechanism is due to diffusion while at medium and higher pressure the dominant loss takes place due to volume recombination. The increase in volume recombination along with diffusion loss gives rise to the charge density decrease [8, 10]. In addition to this effect, the decrease in ionization rate with increase in pressure can also contribute to the decrease of the ion saturation current and electron density.

The Debye length is a characteristic scale length in plasma. It is a measure of the distance that the potential of a charged object penetrates into the plasma. The decrease in Debye length is due to the increase in electron density. The increase in electron density increases the shielding effect at short distance. The variation of Debye length with applied voltage and filling pressure is shown in fig. 6a and fig. 6b respectively.

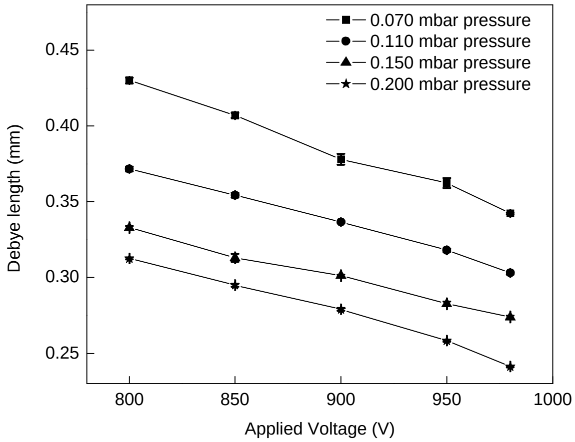

Fig.6a Variation of Debye length with applied voltage at different working pressure

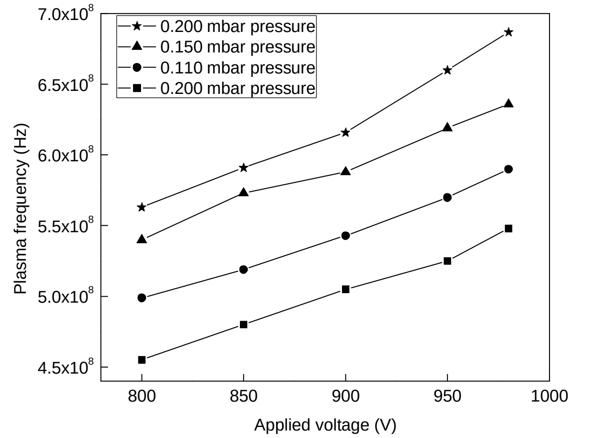

Fig.7a Variation of plasma frequency with applied voltage at different pressure.

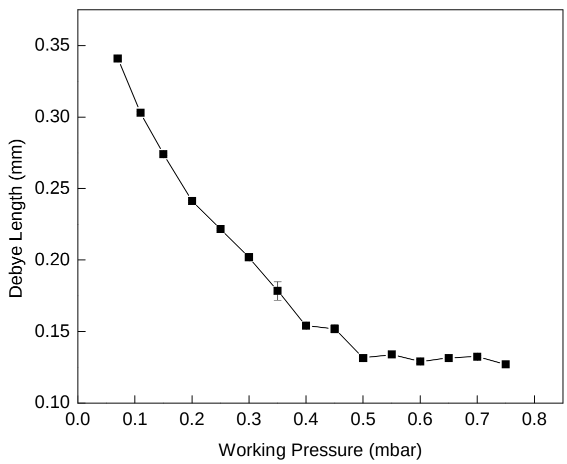

Fig.6b Variation of Debye length with working pressure at constant voltage 980V

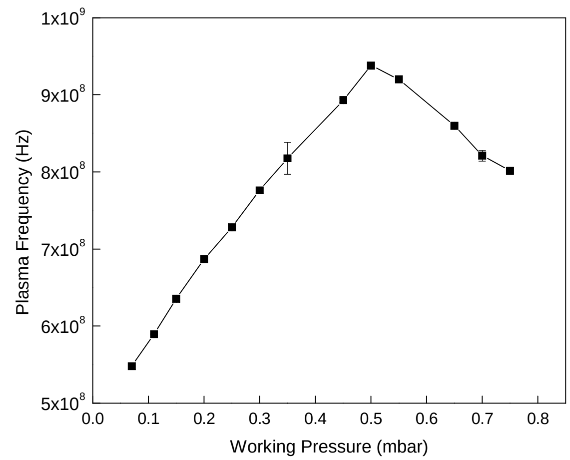

Fig.7b Variation of the plasma frequency with working pressure at constant voltage 980V

The electron plasma frequency is the fundamental characteristic frequency of the plasma and represents the frequency at which the electron cloud oscillates with respect to the ion cloud. As mobility of the electron is always higher than that of ion, electron cloud always oscillate around ion cloud due to electrostatics force of attraction. Increasing the electron density either by increasing pressure or applied voltage increases the oscillating frequency and decrease in electron density also decreases the oscillating frequency of the electron. The variational trend of the plasma frequency is shown in fig. 7a and 7b respectively.

The decrease in floating potential on increasing the voltage and applied pressure is shown in fig. (8a) and (8b) respectively and it is due to the decrease in drift velocity of the bulk of the plasma. Due to frequent collision between electron and neutral species on increasing the pressure and applied voltage, electrons become more and more sluggish and electron flux to the probe decreases. As a result less biased voltage is sufficient to balance the electron flux by ion flux. Hence the floating potential also decreases.

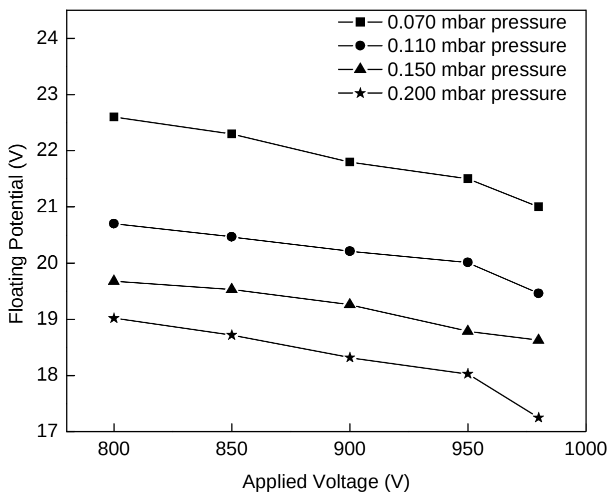

Fig.8a Variation of the floating potential with applied voltage at different pressure

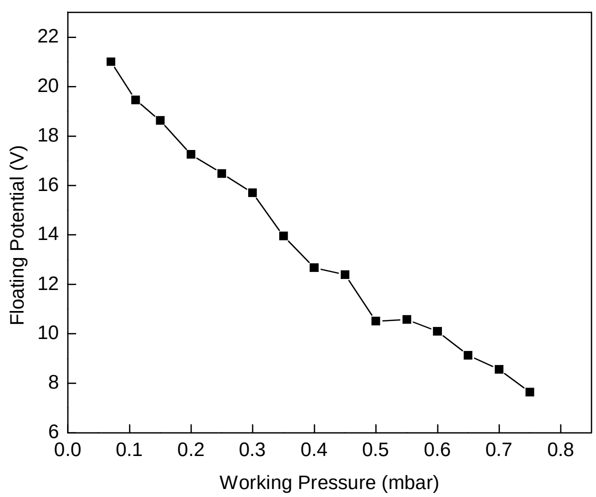

Fig.8b Variation of the floating potential with working pressure at constant voltage 980V

IV. CONCLUSION

In this paper the double probe method is used to characterize the low pressure DC glow discharge in air plasma. First of all electron temperature and ion saturation current are deduced from the *I-V* characteristics at various input voltages from 800 V to 980 V at various fixed working pressure (0.07, 0.11, 0.15, 0.20 mbar) and then these values are used to evaluate electron density, plasma frequency, floating potential and Debye length at the given condition. Similarly, variation of all plasma parameters with working pressure at constant voltage of 980 V is studied and it is found that electron temperature gradually decreases with the increase in working pressure. Similar trends also have been observed in case of floating potential and Debye length. The ion saturation current, electron density and plasma frequency increase and decrease after reaching the maximum value at 0.5 mbar pressure. Volume recombination along with diffusion loss significantly reduces the ion saturation current and electron density after the maximum value at 0.5 mbar pressure.

V. ACKNOWLEDGEMENT

The authors would like to thank Mr. Ram Krishna Rane from Institute of Plasma Research, Gandhinagar, Gujarat, India for his kind help during the experiment and data analysis.

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