STUDIES IN DC GLOW DISCHARGE SYSTEM

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Abstract- The experimental studies of DC discharges in coaxial geometry have shown the presence or absence of a hysteresis in the discharge characteristic curve that is pressure dependent. Nonlinear oscillations have also been observed in these regimes. Thus the main aim of this research work would be to carry out experimental investigations of the plasma characteristics as well as understand the nonlinear aspects of such system using appropriate plasma diagnostics and analysis tools.

Index Terms—DC discharges characteristics, negative differential resistance, floating potential oscillations and dynamical changes in the system.

1. INTRODUCTION

The plasma physics laboratory has been working on the understanding and development of plasma sources, important components in various industrial plasma applications, for the past two and a half decades [1]. The laboratory now looks forward to further these investigations of plasma sources from the perspective of nonlinear dynamics.

Nonlinearity in plasma sources is not surprising as plasma is a highly nonlinear medium and most plasma observations have inherent nonlinear aspects associated with them. In particular, such nonlinear dynamical behavior can be quite prominent in the transition regions of plasma discharges. Nonlinear studies in DC discharges have received extensive attention over the last few decades [2-9]. Recently, oscillations in the floating potential of a Langmuir Probe have been observed in DC discharge systems with coaxial cylindrical electrode geometry [10-14]. However, studies of these oscillations from the perspective of plasma issues were not undertaken in these works, which motivated the present study of the coaxial electrode geometry discharge system in greater detail [15-17] utilizing concepts of nonlinear dynamics.

In this paper, there is an attempt to carry out experimental investigations of the plasma characteristics as well as to understand the nonlinear aspects of such system using appropriate plasma diagnostics and analysis tools.

2. EXPERIMENTAL SETUP

The experimental setup (Fig. 1) consists of a coaxial stainless steel electrode system ($\approx$6 cm long), with the central axial rod (diameter $\approx$ 0.15 cm) being the powered anode and the outer cylindrical tube (inner diameter $\approx$ 4.8 cm) acting as the grounded cathode. The coaxial electrode system rests on a teflon platform at a height of 16 cm from the base of the vacuum chamber (I.D. = 15.0 cm, height = 38.3 cm), in which the electrode system is enclosed. The teflon is shielded from direct contact with the plasma by using a thin mica sheet. The top end of the electrode system is open. The pumping section is at the bottom of the vacuum chamber whereas the top flange has a viewing port (quartz plate of diameter = 9 cm) for carrying out spectroscopic measurements and taking plasma images. The vacuum chamber has three side ports (each of diameter r = 6 cm) at a height of 27 cm from the base of the chamber. One of the side ports is used for inserting the Langmuir probe (as shown in Fig 1) and another is used as an Argon (Ar) gas

inlet port with the vacuum gauges (Micro-Pirani and capacitance manometer) mounted on the third side port. The external circuit is completed through a variable DC power supply (1 kV, 1 A), variable resistances and an ammeter.
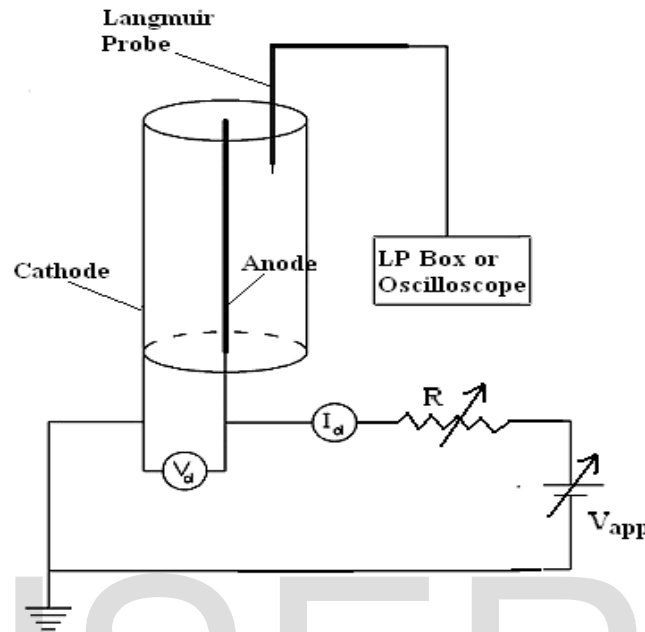

Fig. 1- A schematic diagram of the electrode system and external circuit connection.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In this paper, experiments have been carried out with central anode diameters of 1.5 mm and outer diameters of the grounded cathode being 50 mm, thickness of 1 mm.

3.1 Paschen curve

Fig. 2 shows the Paschen curve [plot of breakdown voltage (V_B) as a function of the product of pressure *(p)* and electrode spacing (*d*)] for argon. Since the inter-electrode distance is fixed, the Paschen curve reduces to a plot of breakdown voltage versus pressure. The above plot exhibits a minimum with respect to *p*, called the Paschen minimum. At large values of *p*, the number of electron-neutral (argon atom) collisions is large and the mean free path is small. Thus the electrons pick up very little energy between collisions and so to compensate this, the breakdown voltage (V_B) rises so that ionization may occur. For small values of *p*, the electron – neutral collisions are few and far between and so it is necessary that almost each collision is an ionizing event. Due to this, the breakdown voltage (V_B) rises again with decreasing *p*.
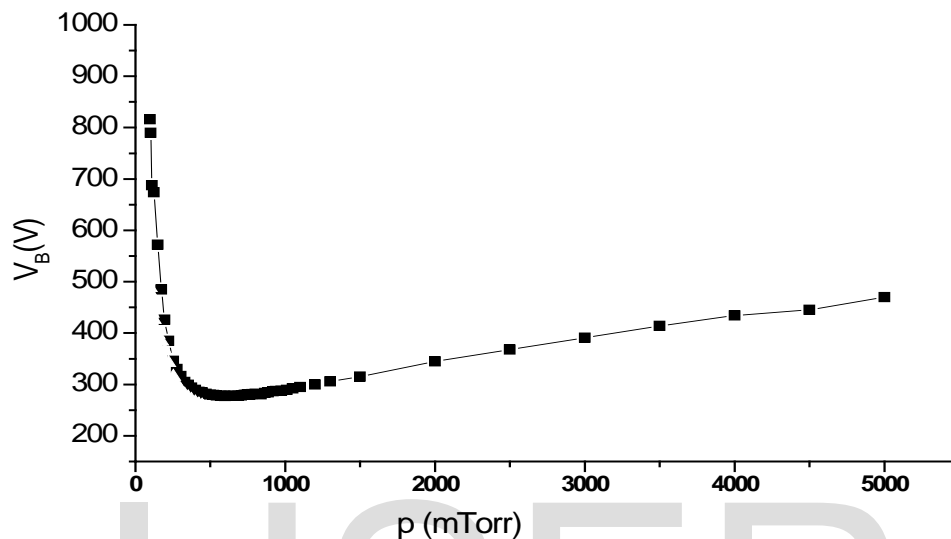
Fig. 2- Plot of breakdown voltage (V_B) for argon as a function of pressure (p) (Paschen curve). This plot was taken with central electrode as anode and outer electrode as cathode.

3.2 I_D vs V_D curve:

A typical V_D - I_D plot for the present system is shown in Fig. 3 for $p \approx 960$ mTorr. The V_D - I_D curve shows the presence of a negative differential resistance (NDR) and hysteresis. Similar plots were also obtained at different pressures (not shown here). In some cases hysteresis was absent while NDR was seen to be present. A detailed experimental characterization of the V_D -I_D characteristics is now being undertaken.
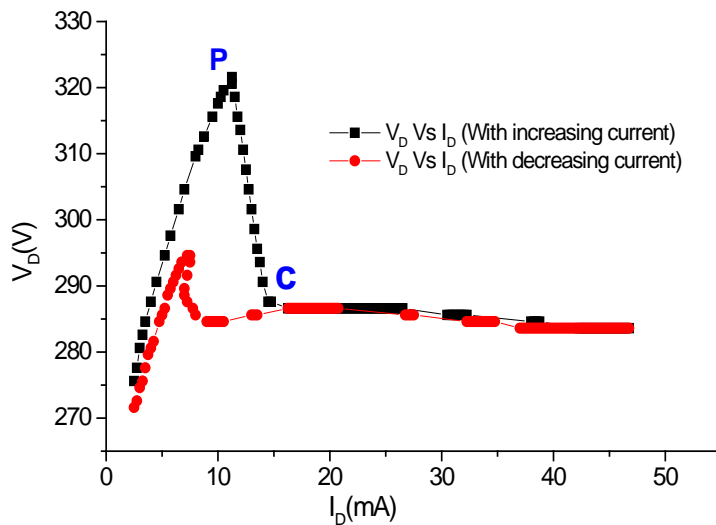
Fig.3- Plot of V_D vs I_D for $p \approx 960$ mTorr

3.3   Langmuir probe measurements

Typical plots which shows the change in the plasma parameters with the radial locations, at specific locations of the V_D - I_D characteristic [before and after the negative differential resistance (point P & point C of Fig.3)] are shown in the following Fig. 4(a) and Fig. 4(b). The plasma parameters determined are the bulk electron density (n_e), bulk electron temperature (T_e), warm electron density (n_w), warm electron temperature (T_w), and plasma potential (V_P).
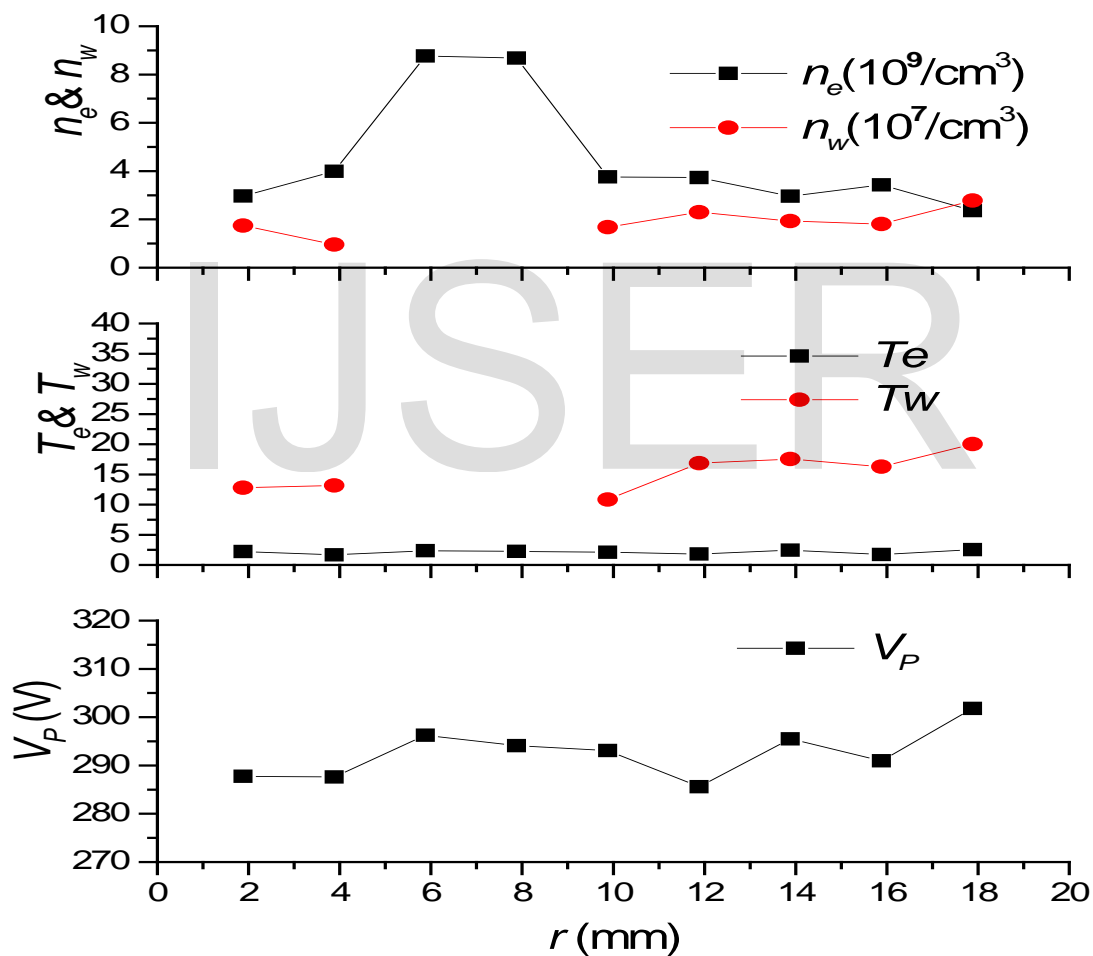

Fig.4(a). Typical plot of plasma parameters vs r (radial distance) at $p \approx 960$ mtorr, $I_D \approx 4.4$ mA, $V_D \approx$ 315 V corresponding to point P of Fig.3

In Fig. 4(a), there are two different electron populations (bulk/ warm) present in the system. The bulk electron density and temperature is $\sim 3 \times 10^9$ /cm^3 and ~ 2 eV respectively but in between 4 mm to 10

mm radial locations, it is considerable higher. Warm electron temperature and density is ~ (2- 3) $\times 10^7/cm^3$ and 10-15 eV respectively. It may be noted that the warm population is absent between 4 to 10 mm at P (Fig.3). The plasma potential varies between 285 V to 298 V.
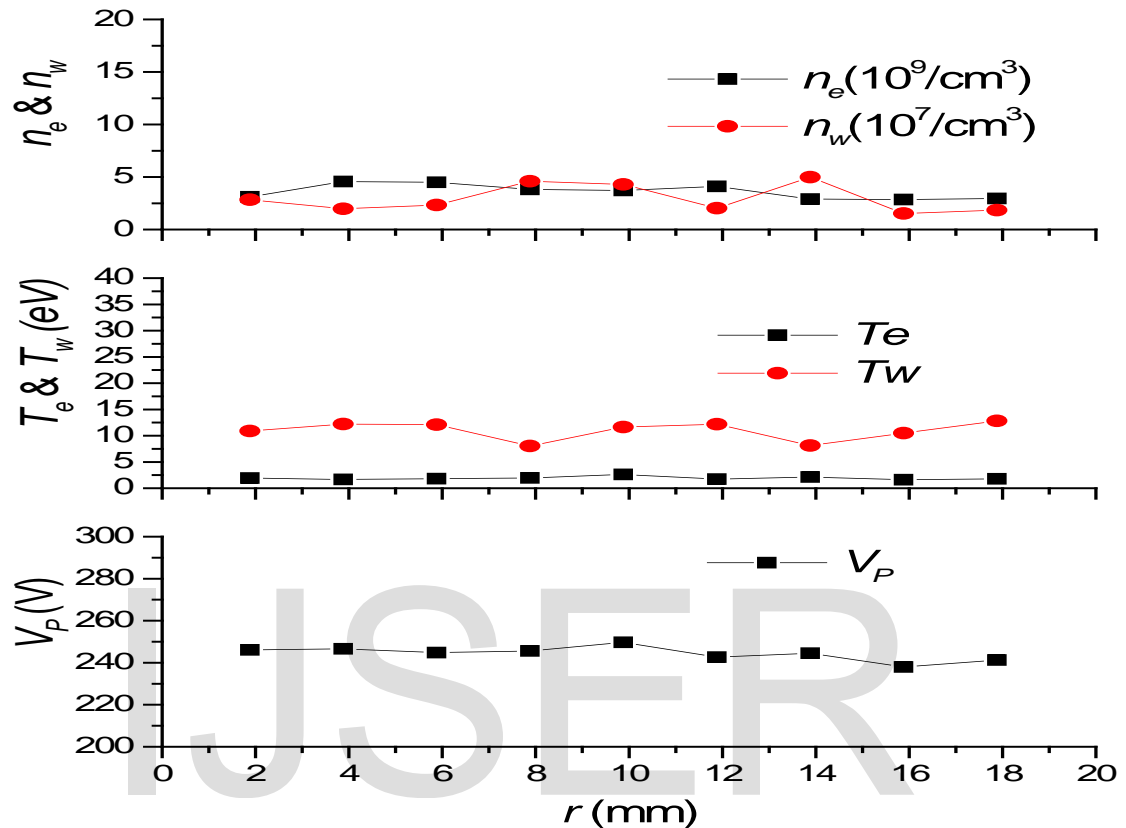

Fig.4(b). Typical plot of plasma parameters vs r (radial distance) at $p \approx 960$ mtorr, $I_D \approx 7.8$ mA, $V_D \approx 283$ V corresponding to point C of Fig.3

In Fig.4 (b), it is noticeable that both (bulk and warm) electron densities and temperatures are present at every radial location at C (Fig.3). The bulk electron density is ~ 3×10^9 /cm^3 but the warm electron density varies between (2.8 - 4.8) $\times 10^7/cm^3$. Bulk electron temperature and warm electron temperature is ~ 2.4 eV and 10-15 eV respectively. The plasma potential varies from 242 V to 248 V.
It may be noted that the plasma potential is obtained for the floating potential (V_f) which is determined values and is given by:

$$V_P = V_f + \alpha T_e$$

$$\alpha = \frac{1}{2} \ln \left(\frac{\pi}{2} \cdot \frac{m}{M} \right)$$

where m(M) is the electron mass(ion mass), For argon ion, α ≈ 5

Summary of plasma parameters:

Plasma parameters	Typical value	
	at point P	at point c
n_e	~ 10^9 /cm^3	~ 10^9 /cm^3
n_w	~ 10^7 /cm^3	~ 10^7 /cm^3
T_e	~ 2 eV	~2.4 eV
T_w	10-15 eV	10-15 eV
V_P	285 V - 298 V	242 - 248 V.

4. FLOATING POTENTIAL OSCILLATIONS

In our system, oscillations were observed in the floating potential of the Langmuir Probe. The nature of the oscillations is different at different pressures and discharge currents. The amplitudes (V_f) and frequencies of these oscillations are seen to vary from 10-1000 mV and 0.5-100 kHz respectively. These oscillations were observed at the specific locations of the V_D - I_D characteristic [before and after the negative differential resistance (point P & point c in Fig.3)] and are shown in Fig.5 (a) & Fig.5 (b). A detailed experimental characterization of these oscillations is now being undertaken.
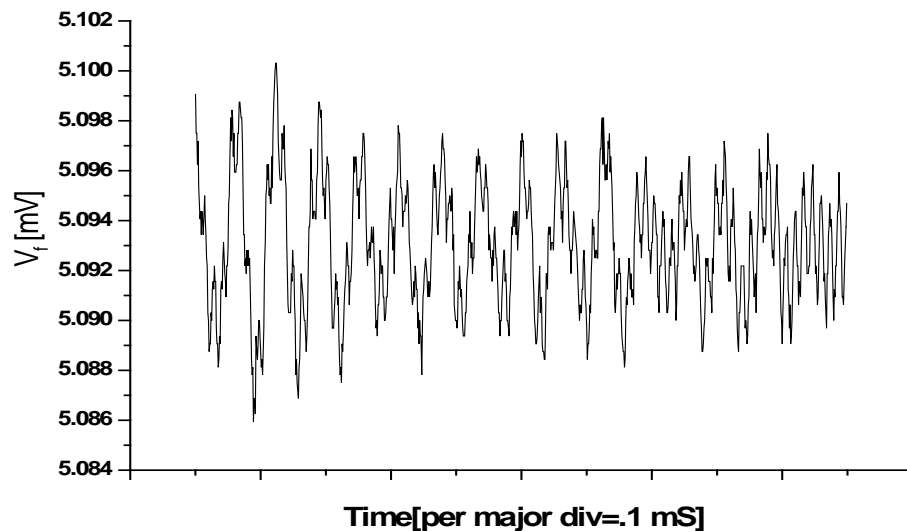
Fig. 5(a). LP floating potential oscillations at point P (Fig. 3), p = 960 mTorr , I_D = 4.4 mA, V_D = 315 V, r = 21.88 mm.
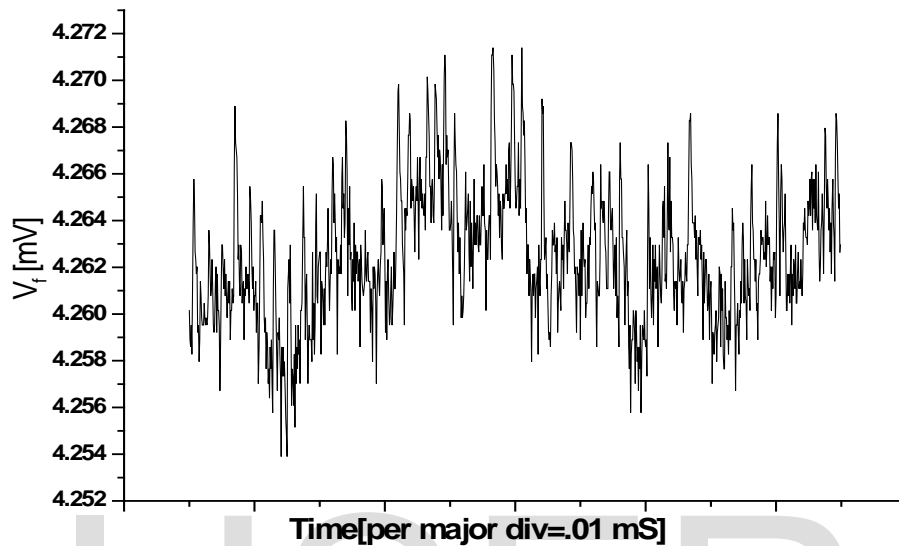

Fig. 5(b). LP floating potential oscillations at point c (Fig. 3), p = 960 mTorr , I_D = 7.8 mA, V_D = 283 V, r = 21.88 mm.

5.   CONCLUSION

The discharge characteristic has a hysteresis effect and the plasma parameters like density, temperature and plasma potential are different before and after the Ist NDR with respect to discharge characteristics. These oscillations which observed are the result of the nonlinear response of the plasma before and after the Ist NDR.

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