CHAPTER 2

2 Experimental Set-up and Diagnostics

2.1 Introduction

The experiments presented in this thesis work have been performed in a low pressure argon plasma. Experiments are carried out to study the plasma response to transient high voltage pulses in a uniform and unmagnetized plasma. This chapter provides the detailed description of experimental set up, the diagnostics used for characterizing the plasma, pulse forming circuit, plasma production and plasma characterization.

The chapter is organized as follows. Section 2.2 describes the experimental device and the pumping system. Section 2.3 describes the method of plasma production. In Sec. 2.4 different diagnostics are described for the characterization of plasma, followed by the plasma characterization in Sec. 2.5. Pulse forming circuit is discussed in Sec. 2.6. Finally a list of references is given.

2.2 Experimental Set-up

In this Section, the experimental set-up used for the excitation of some collective phenomena in a plasma medium is discussed. The set-up mainly consists of a vacuum vessel, a pumping unit, filaments, power supply etc. and these are described in the following subsections.
2.2.1 Chamber and Pumping System

The entire sets of experiments were carried out in a cylindrical vacuum chamber, shown in Figures 2.1 and 2.2. The vacuum chamber is made of stainless steel (SS-304) of 50 cm length and 29 cm in diameter. The chamber has four radial ports of 9 cm in diameter, two axial ports of 13 cm in diameter and eight 10 KF couplers that were used for diagnostics, pumping, connection of gauges, introducing gas into chamber, feeding power to the filaments, viewing, etc..

The chamber was pumped down to a base pressure of $5 \times 10^{-5}$ mbar using a combination of rotary pump (pumping speed = 250 lit/min) and diffusion pump (pumping speed = 500 lit/sec). The Pirani gauge was used to measure the high pressure inside the chamber and the Penning gauge was used to measure the low pressure. The chamber was filled with argon gas (99.999% pure) by a precision gas dosing valve (Balzers made) at a working pressure ($P$) of $1 \times 10^{-3}$ mbar.

![Figure 2.1 Photograph of the experimental set-up. (a) Vacuum chamber. (b) Rotary pump. (c) & (d) are bellows. (e) Diffusion pump. (f) Oscilloscope. (g) Penning gauge head. (h) Penning and Pirani gauge. (i) Langmuir probe shaft. (j) Langmuir probe power supply. (k) Filament heating power supply. (l) Filament bias power supply. (m) High voltage dc power supply. (n) Pulse forming circuit. (o) Argon gas cylinder.](image)
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Figure 2.2 Schematic of the experimental set-up. (1) Vacuum chamber. (2), (3), (5) and (6) are the filaments. (4) Pumping system. (7) and (8) are the SS rings. (9) is the Langmuir probe. (10) Filament heating voltage. (11) Discharge voltage.

Such a working pressure is chosen, so that at $1 \times 10^{-3}$ mbar, the electron-neutral collision mean free path is greater than the vacuum chamber dimension, forming a collisionless plasma. The mean free path can be calculated from the below equation

$$\lambda = \frac{1}{n_e \sigma}$$

where $n_e$ is the gas neutral density and $\sigma$ is the neutral atom cross-section. For a working pressure of $1 \times 10^{-3}$ mbar, the base pressure should be significantly lower than the working pressure. The base pressure can be taken as $5 \times 10^{-5}$ mbar, because at this low pressure the residual gas composition [1] is low and mainly of H$_2$ originating from the metal walls of the vacuum chamber. Such a high vacuum is required to keep reactive gases out of process and to reduce the number of atom/molecule collisions.

First we should discuss the raise of pumping speed number. Pumping speed is one of the important quantities that govern the behavior of all vacuum systems. The relationship can be written as [1]
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\[ Q = S \times P_b \]

where \( Q \) is the gas load or throughput, \( S \) is the pumping speed and \( P_b \) is the base pressure. Gas load is referred to as mass flow while pumping speed is referred to as volume flow. Mass flow is the total number of molecules that a pump has to deal with and volume flow as the volume of gas, a pump can draw at a given pressure. The gas load can be written as \[ Q = R \times A \]

where \( R \) is the out-gassing rate of material and \( A \) is the surface area of the vacuum chamber. Out-gassing rate of stainless steel 304 is \( 8.5 \times 10^{-7} \text{ mbar lit s}^{-1} \text{ cm}^{-2} \) \[2\] and surface area of the vacuum chamber is \( 5.87 \times 10^{3} \text{ cm}^{-2} \). Due to surface roughness and the presence of several ports, \( A \) can be doubled, i.e., \( 1.17 \times 10^{4} \text{ cm}^{-2} \). Now at base pressure \( 5 \times 10^{-5} \text{ mbar} \), the pumping speed would be 200 lit/sec. Keeping margin, the required diffusion pump speed should be greater than the 400 lit/sec.

2.2.2 Cathode and Anode

In our entire experiments the filament was used as cathode. Inside the vacuum chamber, 4 thoriated tungsten (1% thorium and 99% tungsten) filaments of diameter 0.25 mm were mounted on two SS rings (Fig. 2.2). The diameter of the SS rings was 23 cm and the length of each filament was 20 cm. The vacuum chamber was used as anode which was connected with ground.

2.2.3 Power Supply

Power supply is important for production of plasma and excitation of different collective plasma modes. A regulated dc power supply of voltage rating 0 to 32 V and current rating 0 to 30 A was used for filament heating. To produce plasma, another dc power supply of voltage rating 0 to 300 V and current rating 0 to 3 A was used. To excite the electrostatic waves one pulse forming circuit was made. For the pulse forming circuit one high voltage dc power supply of voltage rating 75 V to 1.5 kV and current rating 0 to 0.5 A was used.

2.3 Plasma Production

After filling the vacuum chamber with argon gas at desired working pressure, hot filament discharge plasma was produced. Four thoriated tungsten filaments were connected in
parallel to each other through two SS rings. The filaments were heated by feeding a dc current from a floating dc power supply, such that each filament got a current of 6-7 A and were hot enough to emit thermionic electrons. There was no other electric field to capture these thermionic emitted electrons. So the emitted electrons form the filament, again attracted towards the filament and made a space charge cloud around the filament. To emit these electrons from the filament another dc power supply (Fig. 2.2) was connected in between the filament and chamber wall (grounded). So plasma was generated by impact ionization [3-4] of argon gas neutrals by primary electrons coming out from dc biased hot filaments. The filament bias potential was -65 V and the discharge current was about 0.05 – 0.4 A.

Now we can estimate the plasma parameters and their variation with power, pressure and source geometry from this cylindrical discharge system. The effective area of our cylindrical system is 0.18 m$^2$, which can be calculated from below equation

$$A_{eff} = 2\pi R \left( Lh_R + Rh_L \right)$$

where L is the system length, R is the system radius and $h_R$ and $h_L$ are the ratio of densities reaching at wall compared to bulk plasma and $h_R = h_L \approx 0.3$ for argon plasma [5]. Assuming electrons are Maxwellian in the cylindrical system and the absorbing electrical power is

$$P_{abs} = n_0 e C_s A_{eff} \varepsilon_T$$

where $n_0$ is the plasma density, $C_s = \sqrt{\frac{kT_e}{m_i}}$ is the ion acoustic speed and $\varepsilon_T (= \varepsilon_{\text{collisional}} + 2T_e + \varepsilon_{\text{meanK.E.ion}})$ is the total energy lost per ion from the system. $\varepsilon_T$ is 72 V for argon [5]. For one example, i.e., for $n_0 = 3.92 \times 10^{15}$ m$^{-3}$, $T_e = 6$ eV, $P_{abs} = 30$ W. This is called as uniform density discharge model [5]. For these plasma parameters, discharge voltage is 65 V and discharge current is 0.4 A. So the power absorbed by the system is 26 W, which is closer to the above calculated theoretical value.

### 2.4 Diagnostics

During the past few decades, plasma physics has become established as a major research field. As a result, the field includes a very substantial knowledge covering a wide
variety of branches, from the theoretical to the most experimental study. As with any other science, progress has been made most effectively when an early quantitative confrontation between theory and experiment has been possible. This confrontation places strong demands upon theory to do calculations in realistic configurations and circumstances, but it is also requires that the properties of plasmas be measured experimentally as completely and accurately as possible. For this reason much of the effort in experimental plasma physics is devoted to devising, developing and providing techniques for diagnosing the plasma properties: plasma diagnostics. The overall objective of plasma diagnostics is to deduce information about the state of the plasma from practical observations of physical processes and their effects. To reach useful and accurate results requires rather complete quantitative mathematical and computational analysis; more so sometimes, than in a general text where a qualitative treatment is sufficient.

In 1924 Langmuir [6] presented the basic techniques for investigating plasma parameters with electric probes. He described two basic types: collecting probes or cold probes (Langmuir probe) and electron emitting probes or hot probes (emissive probe). They are simple to construct and allow localized measurements. In our experiments, plasma properties, like plasma density \( n_0 \), electron temperature \( T_e \), floating potential \( V_f \) and plasma potential were measured by using a disc Langmuir probe. In addition, a hot emissive probe was used to measure the plasma and floating potentials. The technical details of the diagnostics are described below.

### 2.4.1 Langmuir Probe

Langmuir probe [4, 6-11] is a diagnostic device used to determine the plasma parameters like electron temperature, electron density, floating potential and plasma potential. This device was named after Nobel Prize winning chemist Irving Langmuir. Mainly the Langmuir probes are used in low temperature plasma [8]. Basically plasma parameters are obtained from \((I-V)\) characteristic of a Langmuir probe, which is described in detail in Section 2.5.

According to Langmuir probe theory, Langmuir probe is a small conducting electrode and it can be a sphere, cylinder or planar. Generally the Langmuir probe inserts into plasma with a constant or time varying electric potential between the probe and the reference. As the charged plasma particles collide with the probe, then the probe draws electrical current which provides the condition of plasma. The amount of current flowing through the probe depends
on the plasma parameters and the probe collecting area. The necessary conditions of Langmuir probe are

1. The probe area should be small, in order to minimize the perturbation of the plasma.
2. The electrode dimension is larger in comparison to the Debye length ($\lambda_D$).
3. The electrons should obey the Maxwellian distribution.

### 2.4.1.1 Construction of Langmuir Probe

Langmuir probe theory is determined by the probe geometry and the sheath dimensions. The relative size of the probe sheath, the probe radius $r_p$ and the collision mean free path $\lambda_m$ in the plasma determine the probe characteristics. A very general requirement for Langmuir probe construction is

$$\lambda_m \gg r_p \gg \lambda_D.$$  \hspace{1cm} (2.1)

The requirement for probe theory is that the probe dimension must be much larger than the Debye length to neglect the edge effect [10]. For disc or planar Langmuir probes the below condition [10] should be satisfied:

$$10 < r_p / \lambda_D < 45.$$  \hspace{1cm} (2.2)

The schematic diagram of Langmuir probe is shown in Fig. 2.3. In our experiments, Langmuir probe consists of a disc electrode of radius 4.5 mm was made up of SS 304. The electrical connection to the probe was provided by a Teflon coated wire which was spot welded to the non-plasma facing side of the probe. Teflon coated wire comes out through a vacuum compatible BNC connector mounted on a SS 304 shaft of outer diameter 5 mm. The SS shaft was introduced into the vacuum chamber through a vacuum feedthrough such that the probe could be positioned at the desired locations inside the chamber.

![Figure 2.3 Schematic of the Langmuir probe.](image)
2.4.1.2 *Langmuir Probe Circuit*

The schematic of electrical circuitry of the Langmuir probe is shown in Fig. 2.4. The circuitry works as follows:

![Schematic diagram of the Langmuir probe circuit.](image)

**Figure 2.4** Schematic diagram of the Langmuir probe circuit.

(a) **Voltage source to bias Langmuir probe**

This circuit consists of a ramp generator that generates a ramp voltage of +40 V to -60 V with a frequency of 50 Hz. This ramp voltage was given to probe along with a dc shift of -1.2 V to -40 V. When the probe was exposed to the plasma it acquired a potential known as the floating potential without drawing any net current. It depends on the state of the plasma and the discharge conditions but not on the probe area. Langmuir probe draws electron or ion current according to the positive or negative potential applied with respect to the floating potential. The dc shift was adjusted accordingly to obtain the required electron or ion current.

(b) **Sensing resistor**

The biasing voltage to the Langmuir probe was applied through a variable sensible resistor (Potentiometer). The resistance could be varied from 1 KΩ to 10 KΩ.
depending on plasma parameters. The potential drop developed across the resistor was measured using a differential amplifier.

(c) Differential amplifier
The voltage drop across the sensing resistor was fed to the input of the differential amplifier circuit. The circuit was developed by using IC OPA27. It is an ultra low noise and very high precision amplifier. The differential amplifier circuit measures the potential difference across the sensing resistor and gives an output, proportional to the current drawn by the probe corresponding to the applied voltage.

(d) Isolation amplifier
Generally, the probe circuits are designed to measure current in those systems where entire circuit may be floating at a higher voltage, in our case the entire circuit described above was kept floating at a high voltage (+40 V to -60 V ramp with a -1.2 V to -40 V dc shift). To measure such current in an oscilloscope with respect to normal ground, this amplifier was used (using IC ISO106B). It isolates two grounds and gives the same voltage drop across the probe resistance with respect to normal ground at the output side.

The output current obtained at the output of the isolation amplifier and the applied voltage was measured with the help of an oscilloscope (Tektronix TDS 2024, 200 MHz and 2 GS/s). The applied voltage to the probe was attenuated through a 10X probe. These data’s could be further stored on a data storage device. This data was used to plot \(I-V\) characteristic to determine the plasma parameters.

2.4.2 Emissive Probe
An emissive probe \([12-16]\) was used to measure the plasma potential or the space potential. An emissive probe is essentially a hot wire (commonly tungsten) inserted into the plasma to measure the floating potential and plasma potential. The schematic diagram of the emissive probe is shown in Fig. 2.5. In our experiment, a tungsten wire of 1 cm length and 0.25 mm of diameter was semi circled. The tungsten wire tips were inserted in a two hole cylinder of ceramic. Copper wires inside the cylinder made compression contact with the replaceable tungsten tip. The emissive probe was heated sufficiently by a floating power supply (150 V and 8 A) with respect to plasma potential to allow thermionic emission of
electrons. The floating potential measured by the emissive probe increased and begun to saturate when it was sufficiently heated up by passing a high current through it. The plasma potential was estimated from the saturated value of the floating potential. The detailed measurement of emissive probe is given in Sec. 2.5.

![Figure 2.5 Schematic of emissive probe.](image)

**2.5 Characterization of Plasma**

**2.5.1 Discharge Parameters**

Tungsten filaments have been widely used in lighting, electronic tubes and as electron emitters for plasma sources. Tungsten is chosen as a thermal electron emitter because of its very high melting point (3683 K). Tungsten is a copious emitter of electrons, when it is heated to a temperature of about 2000 K or more. A tungsten wire is generally directly heated by passing a current through it. The emitted electron current density $J_e$ is limited by space
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charge [17]. For high extraction electric fields (discharge voltage), a saturation current density $J_{\text{max}}$ is reached, which is approximately given by the Richardson-Dushman equation,

$$J_{\text{max}} = A_0 T^2 \exp \left( -\frac{e \phi}{k_B T} \right)$$

(2.3)

where $A_0$ is Dushman’s constant ($1.2 \times 10^6 \text{ A m}^{-2} \text{K}^{-2}$), $T$ is the tungsten filament temperature in kelvins, $e$ is the electron charge, $\phi$ is the work function in volts and $k_B$ is the Boltzmann constant. It can be seen that $J_{\text{max}}$ depends very strongly on the filament temperature. Figure 2.6 shows our experimental plot of saturation electron emission current density versus filament temperature when space charges are absent. The filament temperature was found out by Stefan-Boltzmann law through a simple MATLAB program. From the above observation we saw that on increasing of filament voltage and current, filament temperature increases as well as electron emission current density. For a given filament temperature, the electron emission increases linearly with filament diameter [18].

The variation of discharge voltage with discharge current at constant pressure is shown in Fig. 2.7. The filament glow covers the whole chamber and this $I-V$ characteristic is plotted for various filament heating currents. The discharge current increases rapidly with increase in voltage and saturates from near about 40 V. This saturation occurs because of no additional thermionic emission from filament on increase of discharge voltage for a fixed filament current.

![Figure 2.6](image)

**Figure 2.6** Typical filament temperature versus emission current density for the filament diameter of 0.25 mm.
When a tungsten filament is used as a thermal electron emitter, it is important to know the relationships among the filament diameter, heating current, filament temperature, emission current and life time. The life time of a tungsten filament is generally defined as the time required evaporating away 10% of the original diameter [18]. The evaporation rate is a function of filament temperature [19]. So in a filament discharge plasma, the number of electrons that can be extracted from a hot filament is proportional to $J_i$ (ion current density), which is a function of the plasma density, the plasma temperature and the extraction voltage [20-21].

### 2.5.2 Plasma Parameters

A single Langmuir probe [4, 6-11, 22-29] was used to measure the plasma parameters like, plasma density ($n_0$), electron temperature ($T_e$), floating potential ($V_f$) and plasma potential ($V_p$). The probe construction and validity of probe theory to our experimental situation have been discussed in Sec. 2.4. The below described Langmuir probe theory is valid for only in the absence of drifting electrons [26]. In addition, an emissive probe was also used to measure plasma potential. The details of measurements are described below.
2.5.2.1 Determination of Plasma Parameters Using Langmuir Probe

Langmuir probe is merely a small metallic electrode inserts into the plasma, with a constant or time varying electric potential between the probe and the surrounding chamber. For a probe inserted into the plasma, as the voltage on the probe is biased negatively and positively, the I-V characteristics of the probe can be plotted.

![I-V characteristic for a Langmuir probe](image)

The ideal I-V characteristic for a single probe is shown in Fig. 2.8. When probe bias $V$ is negative with respect to plasma potential $V_p$, current drawn by the probe from the plasma is positive. The electric field around the probe, confined to the ion sheath will prevent all the energetic electrons from reaching the probe, this causes effectively reducing of the electron current to zero. So, the point at which entire current collected by the probe is due to positive ions. This point is called ion saturation current $I_{is}$ which is given by

$$I_{is} = n_i e A_p C_s$$  \hspace{1cm} (2.4)

where $n_i$ is the ion density at the sheath edge, $A_p$ is collecting area of the probe, $e$ is electron charge and $C_s$ is ion acoustic speed or Bohm speed. Bohm speed is the speeds at which ions are enter to the sheath and is given by

$$C_s = \sqrt{\frac{k_B T_e}{m_i}}$$  \hspace{1cm} (2.5)
where \( m_i \) is the ion mass. The ion saturation current density can be calculated from below equation

\[
J_{is} = n_i e \sqrt{\frac{k_B T_e}{m_i}}.
\]  

(2.6)

As increase in probe bias (probe bias made more positive), increases the number of electrons which is able to overcome the repulsive electric field. So negative (electron) current increases exponentially and overall current collected by the probe decreases. Eventually the electron current equals to \(-I_{is}\). So that the total current is zero. The potential at this point is known as floating potential and is given by \[3\]

\[
V_p - V_f = \frac{1}{2} \left( \frac{k_B T_e}{e} \right) \ln \left( \frac{m_i}{2 \pi m_e} \right)
\]  

(2.7)

Further increase of probe bias to \( V_p \) allows the electron current to increase. This current is given by

\[
I_e = en_e A_p < u_e >
\]  

(2.8)

where \(< u_e >\) is the average electron thermal velocity and is given by

\[
< u_e > = \sqrt{\frac{k_B T_e}{2 \pi m_e}} \exp \left( \frac{e V_{sh}}{k_B T_e} \right)
\]  

(2.9)

where \( V_{sh} = V_p - V \) is the sheath potential. At \( V_p \) electrons are unrestricted from being collected by the probe. Any further increase in bias will simply add energy to electrons, not the current drawn. Current at this point is called electron saturation current \( I_{es} \) and is given by

\[
I_{es} = en_e A_p \sqrt{\frac{k_B T_e}{2 \pi m_e}}
\]  

(2.10)

The inverse of the slope of the steep portion of the graph between logarithm of the electron current and the potential on the probe will give the electron temperature and is given by
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\[ T_e = \frac{dV}{d(ln I_e)}. \]  

(2.11)

After obtaining electron temperature from logarithmic graph of current versus potential and ion saturation current from \( I-V \) characteristics and putting the values in Equation (2.4), plasma density can be calculated.

In our experiment, first the single disc Langmuir probe was biased with a sweep voltage to draw the probe current at a discharge voltage of -65 V and current \( I_{dis} = 0.3 \) A at \( P = 1 \times 10^{-3} \) mbar. A resistance connected in series to the probe was adjusted in such a way that it can draw sufficient current. The applied probe voltage and the probe current are shown in Fig. 2.9.

Figure 2.10 shows the experimental \( I-V \) characteristics of the Langmuir probe. The voltage corresponding to the zero probe current gives the floating potential as -4V. The ion saturation current is about 30 µA. The electron collection region gives the information about electron temperature and plasma potential.

![Figure 2.9](image)

**Figure 2.9** The upper trace shows the voltage wave front applied to the probe and the lower trace shows the current drawn by the probe.
Before calculating the electron temperature, we have eliminated the contribution of ion current by subtracting a dc voltage equivalent to ion saturation current from the entire probe characteristics. Assuming the electron are Maxwellian at the transition region or the steep region (the region where the probe current changes significantly with probe voltage) of the Langmuir characteristics. Figure 2.11 is the logarithm of electron current (steep region of Fig. 2.9) versus the probe voltage. The inverse of the slope gives the electron temperature, i.e., 2.04 eV at that particular discharge condition.

Putting the values of ion saturation current and electron temperature in Eq. (2.4), the plasma density is $2.65 \times 10^{15} \text{ m}^{-3}$. Putting the value of electron temperature in Eq. (2.7), the plasma potential for argon gas is +6 V. Again in Fig. 2.10, the electron current saturates at around +7.5 V. Hence the plasma potential is +7.5 V, which is slightly greater than the calculated value. It is to be noted that the plasma parameters vary with the filament heating voltage, current and filament lifetime.
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Figure 2.11 Natural logarithmic of electron current versus probe voltage.

Figures 2.12 and 2.13 show the axial and radial variation of electron temperature and plasma density respectively. The plots show that the variation in $T_e$ and $n_0$ is very low, indicating an almost uniform plasma inside the chamber.

The plasma which is considered in our study, are unmagnetized, uniform and non-equilibrium, with ions and electrons having different temperature ($T_e >> T_i$).
2.5.2.2 Plasma Potential Measurements by Using Emissive Probe

The most common method is to determine the plasma potential from the knee of the electron saturation current in the I-V characteristic curve of the Langmuir probe (cold probe). However, this Langmuir probe approach yields incorrect results if the plasma electrons are drifting or if the probe surface is contaminated giving rise to a change in the work function. On the other hand, emissive probe methods can still yield correct results if the plasma electrons are drifting. Unlike collecting probes, emissive probes don’t give useful data on plasma density.

In addition to a Langmuir probe, a hot emissive probe was used for measuring floating and plasma potentials [12-16]. Electron temperatures were also estimated from the difference of these two potentials using Eq. (2.7) and compared with the temperature obtained from Langmuir probe data. Several different procedures have been developed to obtain the plasma potential from emissive probe, i.e., (1) Inflection point method [14-15] and (2) Floating potential method [12].

A simple method was used in our experiment to determining the plasma potential from the floating potential using an emissive probe. This method is applicable when the electron temperature is substantially greater than the used tungsten wire temperature. This
method was based on the observation that the floating potential of an emissive probe depends on wire temperature. A wire temperature which changed in time caused the floating potential also to vary.

In our experiment, the emissive probe was made of a tungsten wire of 1 cm length and 0.25 mm of diameter and was inserted into plasma. The floating potential obtained without heating the emissive probe is equal to floating potential of cold probe. When the emissive probe was heated by various heating currents (or voltages) in ascending order, then the floating potential was also varied. The floating potential was saturated for large heating currents, as shown in Fig. 2.14. This saturated floating potential is the plasma potential.

When the emissive probe heating voltage is less than the plasma potential \( V_w < V_p \), then there is no potential barrier to obstruct the emitted electrons from the hot tungsten wire. So the emitted electrons can be added to the plasma below \( V_p \) and floating potential changes. As one exceeds \( V_p \) the flow of electrons from the probe is rapidly reduced by a potential barrier and no variation in floating potential, which is called as plasma potential.

![Figure 2.14 Emissive probe heating current versus floating potential.](image-url)
This emissive probe experiment was done for the discharge current of $I_{dis} = 0.3$ A at $P = 1 \times 10^{-3}$ mbar. From the graph the saturated floating potential, i.e., the plasma potential is +7 V, which is approximately equal to Langmuir probe data plasma potential. If we put the emissive probe measured floating potential (-3.8 V) and plasma potential (+7 V) in Eq. 2.7, then electron temperature is 2.16 eV, which is nearly equal to Langmuir probe data.

### 2.6 Pulse Forming Circuit

The pulse-forming circuit is described in Fig. 2.15. For the experimental requirements the values of the capacitor ($C$) and the resistor ($R_2$) were adjusted in such a way that the pulse duration always satisfied for the conditions $\tau_p < f^{-1}$ and $\tau_p > f^{-1}$ and the pulse height was decided by the voltage to which capacitor was charged. The value of the inductor ($L$) was fixed. The positive or negative pulse can be obtained by changing the polarity of HV dc supply.

In our case, $R_1$ was chosen according to HV dc supply current and voltage ratings. In our case, the voltage and current ratings of dc supply was 1.5 kV and 0.5 A respectively and $R_1$ was 3 kΩ. The value of $R_2$ was fixed (50 Ω) and it was a thin-film non-inductive resistor. Only the value of $C$ was varied for changing the pulse width. For example, for 140 ns pulse width the capacitance was 0.71 nF. The inductor (320 nH) was used for blocking the high frequency signals (noise) in the voltage signal, which acts as a low pass filter.

A spark gap was used in the pulse forming circuit. A spark gap consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air. This is designed to allow an electric spark to pass between conductors. When the voltage difference between the conductors exceeds the gap’s breakdown voltage, a spark forms, ionizing the gas. An electric current then flows until the ionized gas path is broken or the current reduces below a minimum value called the “holding current”. This usually happens when the voltage drops. During the action of ionizing the gas, it leads to sound, light and heat. Spark gaps are generally used to prevent voltage surges from damaging equipments. So spark gaps are used in high voltage switches, i.e., can be used to rapidly switch high voltages and high currents for certain pulsed power applications. In our pulse forming circuit, the spark gap was used instead of electrical switches like thyristor, to keep the circuit floating and easily accessing of a single pulse. But in case of a conventional thyristor, once it has been
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switched on by the gate terminal, the device remains latched in the on-state (i.e., doesn’t need a continuous supply of gate current to conduct or we can say its output may depend not only on its current input, but also its previous inputs). As long as the anode remains positively biased, it can’t be switched off, until the anode current falls below the holding current (or a thyristor can be switched off if the external circuit causes the anode to become negatively biased). So in our case the spark gap was used.

One typical voltage pulse is given in Fig. 2.16 using the pulse forming circuit.

![Figure 2.15 The pulse forming circuit.](image)

**Figure 2.15** The pulse forming circuit. [HV dc Supply = high voltage dc supply (1.5 kV, 500 mA), R\(_1\) = resistor (3 kΩ), C = capacitor, R\(_2\) = load resistor, L = inductor (320 nH), P\(_1\) = electrode or the exciter].

![Figure 2.16 A typical voltage pulse obtained from the pulse forming circuit.](image)
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2.7 References

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