Chapter 2

EXPERIMENTAL SETUP AND DIAGNOSTICS

The experiments were performed in a double plasma machine modified accordingly, for the different experiments. A schematic of the device used in the double layer experiments is shown in fig.2.1. The entire vacuum system was made of stainless steel cylindrical chamber, pumped down to a base pressure of about $1 \times 10^{-5}$ Torr. In the following sections, we describe the plasma sources, the diagnostics etc., that were housed inside the vacuum system, also dealing briefly with the construction of these diagnostics and the electronics circuitry necessary.
Figure 2.1 Schematics of the double plasma device. Drifting electrons are produced by biasing the source chamber negative with respect to the target chamber. Filaments are placed in the source chamber only. Collecting Langmuir probe and the emissive probe are placed in the target chamber. Grids G1 and G2 are maintained at 0V in the normal mode of operation, and are maintained positive with respect to the adjacent sources. Grid G3 is usually grounded.
2.1 Plasma Sources

The double plasma machine comprised of two plasma chambers. One is the source plasma and the other target plasma. The source plasma was made of a cylindrical mesh chamber of 30 cms long and 30 cms diameter. The mesh chamber itself served as the anode. About 20 tungsten filaments, 8 cms long, were mounted inside the cylindrical chamber. To achieve uniformity of the plasma, the filaments were positioned at equal intervals in a circular configuration, along the periphery of the chamber. The filaments were electrically isolated from the anode body, by porcelain washers. This structure was in turn housed in the vacuum system of 50 cms diameters and 125 cms long. The tungsten filaments were heated to thermionic emission and a steady state discharge was maintained between the filaments and the anode mesh, by accelerating the electrons to about 50-60 volts. The filament heater current was about 150 Amperes at about 10 volts.

The target region did not contain a separate filament source. The high energy drifting electrons from the source maintained the plasma in the target region, by electron-neutral impact ionisation. The target and the
source plasmas were electrically isolated by a grid assembly consisting of two wire meshes of about 70% to 80% transparency. This grid assembly was mainly used as an accelerating structure for the electrons, and also prevent density gradient, that could be present with a single grid. The cross flow of charged particles is prevented by appropriately biasing the grids. As a result, the source and target plasmas could be maintained at different potentials. Depending on the nature of the experiment, we could inject an electron or ion beam by appropriately biasing the source plasma. An end grid G3 was provided at the end of the target plasma, and grounded. The sheath around this grid, helps in maintaining the trapped particle population.

The whole vacuum unit was pumped down to a base pressure of $1 \times 10^{-5}$ Torr. Different pumping arrangements like pumping from the target section, or source section, were deployed. Their advantages are explained in detail, later in the thesis. The grids were usually biased positive, with respect to their adjacent chambers. For e.g. G1 was biased positive with respect to the source, and G2 biased positive with respect to the target. In some cases, both the grids G1 and G2, were
biased positive with respect to the source. The results, obtained from both the configurations are described later chapters of the thesis.

The experiments on rarefaction waves, in a homogeneous plasma, were carried out in an uniform plasma produced as explained above. A grid of a diameter of 20 cms was used to launch the waves. The experimental set up will be explained in detail in Chapter 5 of this thesis.

2.2 Diagnostics

The diagnostics comprised of a hot emissive probe for plasma potential measurements, a cold Langmuir probe for density, temperature and electron energy distribution measurements. A retarding potential analyser was deployed for ion energy distribution measurements. A detailed account of each of these diagnostics is described below.

2.2.1 Plasma potential measurements using an emissive probe

Electron emitting probes have been used to determine the plasma potential quite accurately to the order of the wire temperature. Its advantage in potential measurements lies in the fact, that it responds to only
particle potential energy unlike the collecting Langmuir probe, which senses both the potential and kinetic energies, of the particles.

An emissive probe forms a diode with a plasma in which it is immersed, but in addition to electrons, we also have ions which are collected by the probe depending on the bias voltage. When the probe is hot and biased below the space potential it emits electrons into the plasma and also collects plasma ions. When biased above the plasma potential it collects electrons from the plasma. The point at which the transition from hot to cold probe takes place is called the inflection point and this point gives the plasma potential.

Several authors (Chen 1965, Kemp and Sellen 1966, Smith et al. 1979) have proposed various methods to determine the plasma potential. The floating potential (Kemp and Sellen 1966) method can be used to determine the space potential of the plasma. The point at which the hot probe deviates from the cold probe (cross-over point) gives the plasma potential. The plasma potential determined from the emission characteristic also gives a good measure of the plasma potential. The double cross technique (Smith et al. 1979), where the plasma potential
is measured from the collection and emission characteristics gives an accuracy of the order of wire temperature.

Both plasma and wire temperatures are obtained from the same probe characteristic. In the experiments on potential double layers, we used the hot probe, for space potential measurements, with high spatial resolution. Some preliminary investigations were carried out to determine the best method of measurement as presented below.

2.2.2 Probe construction and mode of measurement

The probe construction is shown in fig. 2.2. The Block diagram of the electronics used to determine the probe characteristic is given in fig. 2.3, with the timings diagram presented in fig. 2.4. The probe is heated by a half-wave rectifier output which also triggers the comparator, and the measurements are carried out during the off-half cycle to keep the probe at a uniform potential. The probe is biased by a sweep of -28.0 volts to +14.0 volts of 5 seconds duration. The probe current is sampled at various bias voltages, using pulses of 50 microseconds width, using a Boxcar integrator operated in the sampling mode. The output or its differential can be directly recorded on a X-Y recorder.
Figure 2.2 Design of the emissive probe construction.
Figure 2.3 Block Diagram of the electronics used in the probe characteristic determination. The probe is heated by a half-wave rectifier output which also triggers the comparator, and the measurements are carried out during the off-half cycle to keep the probe at uniform potential.
Figure 2.4 The timings diagram for probe current sampling. The probe is biased by a sweep of $-28 \text{ V}$ to $+14 \text{ V}$ of 5 seconds duration. The probe current is sampled at various bias voltages using pulses of 50 seconds width, using a Boxcar in the sampling mode. The output is directly recorded on a X-Y recorder.
The characteristics have been obtained in the plasma sources described above. The differentiated curve is also recorded on the same graph. The density is varied by varying the discharge current from 1.8 Amp to 0.3 Amp resulting in a density change by an order of magnitude. The plasma potentials determined by double cross technique are compared with that obtained by the first differential.

2.2.3 Results and Discussion

The probe emission data for 150 volts is given in Table 2.1. Fig. 2.5 shows the probe characteristic at a density of $10^9$/cm$^3$ and fig. 2.6 at a density of $10^8$/cm$^3$. It is found that at a density of $10^9$/cm$^3$, $I_e$ Sat/$I_c$ Sat < 1, and the plasma potentials determined by the three methods i.e. from the collection characteristic, emission characteristic and the peak of first differential, are almost of the same order only differing by an order of the wire temperature. At a density of $10^8$/cm$^3$, $I_e$ Sat/$I_c$ Sat $\approx$ 1, the three methods yielded three different potentials. This has been found to be prominent only at low densities i.e. at $10^8$/cm$^3$ and increasing the probe filament voltage does not affect much, since the collection saturation characteristic does not change much though $I_e$ Sat/$I_c$ Sat < 1.
### TABLE 2.1

**PROBE EMISSION 150 VOLTS**

<table>
<thead>
<tr>
<th>Collection potential</th>
<th>Emission potential</th>
<th>Plasma</th>
<th>Plasma</th>
<th>Plasma</th>
<th>Electron temperature</th>
<th>Wire current</th>
<th>Density</th>
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<td>sat. I_e/I_c (Saturation characteristic)</td>
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<td>5.0 4.5 0.9 3.8 4.2 4.2 2.4 0.4 1 1.6 x 10^9</td>
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<td>2.5 2.5 1.0 -2.2 +1.2 -1.0 -1.8 0.4 25 4.5 x 10^8</td>
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<td>3.3 3.3 1 -1.9 -0.5 -0.1 2.6 0.4 10^9</td>
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Figure 2.5 I-V characteristic of the emissive probe and the first differential at a density $n \approx 10^{17}$ cm$^{-3}$.
Figure 2.6 I-V characteristic of the emissive probe and the first differential at a density $n \approx 10^{8}$ cm$^{-3}$. 
The discrepancy in this result at low densities is that the sheath size increases and hence presents almost a planar surface to the plasma. Thus there is a transition from cylindrical probe characteristic to a plane probe characteristic.

The Half width Half maximum (HWHM) of the differentiated peak is supposed to give the probe temperature, but this is also true only at higher densities of the order of $10^9$/cm$^3$, whereas at low densities of the order of $10^8$/cm$^3$, the width becomes very broad, leading to incorrect determination of probe temperature directly.

It is also noted that between densities $10^8 - 10^9$/cm$^3$, $I_e\text{ Sat}/I_c\text{ Sat} > 1$, where the emission characteristic gives the same potential as the first differential. From the above observations, we can conclude that the double cross technique is useful at higher densities $> 10^9$/cm$^3$ with $I_e\text{ Sat}/I_c\text{ Sat} < 1$, where the measured potentials are of the same order as that of the first differential. Finally we observed that the floating point method (Kemp and Sellen, 1966) yielded potential measurements as accurate as the first differential method even at low densities. Hence we employed this scheme of measurement in all our observations.
2.3 Cold Langmuir Probe

The cold collecting probe of 1.2 cms diameter, made of tungsten disk, was used to measure plasma density, electron temperature and distribution functions.

2.3.1 Temperature measurement

The block diagram of the electronics used to determine the I-V characteristic, and distribution functions is shown in fig. 2.7. The probe was applied a ramp voltage from -20V to +20 volts, and the current-voltage characteristics (I-V) were directly obtained on the X-Y recorder or the oscilloscope. The temperature was obtained from the formula

\[ kT_e (eV) \approx \frac{d(eV_p)}{d(ln I_{probe})} \]  

(2.1)

\( k \) is the Boltzmann constant, \( V_p \) probe bias potential, \( I_p \) is the probe current.

2.3.2 Density measurement:

The probe was biased to large negative values to collect ion saturation current. The density was obtained from the eqn. (2)

\[ N_e = \frac{(I_{ion})_{sat}}{eV_i \cdot A} \]  

(2.2)
Figure 2.7 Block diagram of the electronics deployed in obtaining the I-V characteristic and the distribution function of a collecting Langmuir probe.
(I_{ion})_{sat} - Ion saturation current, v_i - ion acoustic velocity = \sqrt{\frac{2kTe}{M_i}} \text{ cms/sec.} \quad A - Area of the collecting probe in cm^2, M_i = Mass of argon ion.

2.3.3 Electron Energy distribution

The I-V characteristic, thus obtained as mentioned above, was differentiated electronically, to yield the energy distribution function f(V), as explained below:

Let the electron current collected be

\[ I_p = nev \quad (2.3) \]

where \( I_p \) is the current,

n is the density

v is the velocity of the electrons due to the applied potential.

In terms of the velocity distribution function, density n can be written as

\[ n = \int f(v)dv \quad (2.4) \]

Substituting this in eqn. (2.1)

\[ I_p = e \int f(v)v dv \quad (2.5) \]

This can be written in terms of energy due to the applied potential as
\[ I_p = \frac{e^2}{m} \int f(V_p) \, dV_p \]  

(2.6)

\( V_p \) is the potential applied to the probe

Differentiating equation (6) we get

\[ \frac{dI_p}{dV_p} = \frac{e^2}{m} f(V_p) \]  

(2.7)

Hence

\[ \frac{dI_B}{dV_p} = \frac{e^2}{m} f(V_p) \]  

(2.8)

In general, equation (8) can be written as

\[ f(V) = \frac{m}{e^2} \frac{dI}{dV} \]  

(2.9)

Hence from equation (9), we find that the first differential of the I-V curve yields the electron energy distribution.

2.4 Gridded Energy Analyser

A retarding potential analyser (RPA) consisting of grids and a collecting disk was deployed to monitor the ion energy distribution functions. The dimension of the RPA was about 3 cm long and 2 cm diameter. The RPA used in our system consisted of one grid and a collecting disk. The outer enclosure was left at floating potential to repel ions. The grid mesh was applied a negative potential to collect ions, but repel electrons. The potential
on the collector was varied and the ion current was monitored with respect to the collector potential. The first differential of this I-V curve yielded the ion distribution function. The ion temperature measured with this analyser was about 0.2 eV.

2.5 **Probe Configurations**

In addition to the individual probes, we had mounted a cold Langmuir probe and a hot emissive probe, on the same shaft one slightly above the other. The shaft was insulated and placed along the wall of the system, to minimise the disturbances, to the bulk plasma. The advantage in this arrangement, is that, in the presence of a double layer, the plasma potential and the corresponding distribution function can be measured simultaneously, at a particular point.