Chapter 4

Characterization of ETG Plasma

Plasma source for large plasma device is based upon the use of heated filaments as
the source of primary electrons. The device is dedicated to the study of electromagnetic
response of the plasma [21]. Specifically, problems related to excitation and
propagation of Electron Magnetohydrodynamic (EMHD) structures were studied in
this device [69]. Both linear and non-linear structures were excited and propaga-
ted. It was found that non-linear structures are robust [25]. Non-existence of
non-linear effects are in contradiction of the observation of electromagnetic turbu-
ulence in EMHD regime.

It was shown that gradients in density act as a driver for excitation of this turbu-
ulence. To expand the understanding of electromagnetic turbulence, we had planned
experiments wherein scale length of density gradients can be controlled by control-
ing the source function of primary electrons. In the very first attempt, we provided
an electron source that has the same electron emission capacity as in the earlier
source but is not distributed over the cross-section of LVPD. However, this gave
us a plasma that has a density gradient nearly the same as in the earlier source,
but an entirely new feature in the electromagnetic turbulence. It was found [see
chapter 5] that turbulence peaks in the region of flat density. This implies that
density gradient cannot be driver for the observed fluctuations in the core of LVPD.
This led to a search and identification of the driver of the observed turbulence. We
have now identified the driver to be gradient in electron temperature. This chapter
describes the characteristics of the plasma with the temperature gradient. These
characteristics are compared with the plasma characteristics of earlier source.
4.1 Experimental Conditions

Plasma is produced in a uniform axial dc magnetic field, $B_z = 6.2 \text{ G}$. Axial confinement is provided by a set of two cusped end plates (anodes) having broken line cusp. A pulsed discharge of Argon ($V_d = 65 \text{ V}, I_d \approx 400 \text{ A}, t_{\text{pulse}} \sim 9.2 \text{ ms}$) is produced with a repetition rate of 1s. A burst of 8 such pulses are superimposed to reduce the statistical error. Plasma of density, $n_e \sim 10^{11} \text{ cm}^{-3}$, electron temperature, $kT_e \leq 8 \text{ eV}$ at a pressure of $P = 4 \times 10^{-4} \text{ Torr}$ is produced using two multi-filamentary plasma sources of different geometrical shapes.

Cathode emission is distributed over 60 cm $\times$ 60 cm by employing 26 filaments in the case of broad source is reduced to 3.8 G at the position of filaments. In case of narrow source, the area of emission is kept the same as in broad source. However, filaments are arranged to cover an extent of 4.5 cm $\times$ 12 cm in comparison to 60
cm x 60 cm for the broad source. Details about device and auxiliary systems along with various other subsystems have been discussed in chapter 2.

4.2 Typical plasma shot

Argon plasma is produced by impact ionization of the energetic electrons (kinetic energy = 65 eV) with the background neutrals. Typical temporal plasma discharge is shown in figure (4.1). It shows temporal development of discharge current, ion saturation current, axial diamagnetic field and floating potential. These measurements are undertaken using Langmuir probes and miniature bifilar multi-turn magnetic loops on the axis of the device, axially at $z = 120$ cm from the source.

The discharge current builds up to 200A over a time duration of $< 1ms$, remains steady over the remaining period and when the arc voltage is turned off, it falls to zero in about $20\mu s$. Hence temporal behavior of the plasma can be divided into
three main parts. These are the formation region, the main glow and the after glow.
The ion saturation current, which is an indicator of plasma density, nearly mimics
the discharge current up to the point the arc voltage is switched off. It reaches its
maximum in few ms after the initiation of the discharge pulse. We notice that the
plasma decays with an e- folding time of 0.4 ms, after the power supply for arc is
switched off. This indicates that plasma confinement time is 0.4 ms.

The floating potential exhibits large negative values within 150 – 300μs [see fig
4.1(d, h)]. This is followed by a slow decay to a stable low value. Similarly, the
floating potential has a sharp fall over 100μs, in the after glow, followed by a slow
decay in the same manner as that of ion saturation current. The sharp negative
peak in the plasma is indicative of charging of plasma by the energetic electrons.
As the plasma density builds up, the floating potential increases from -45V to -25V
indicating that energetic electrons are used up in causing ionization and excitation
of Argon atoms.

Figure 4.3: Temporal profiles of ion saturation current using narrow and broad sources
at different radial locations.
Figure 4.4: The spatio-temporal evolution of the density in the case of two electron functions. Symbol '+' for the narrow source and '*' for the broad source are used for representation.

Figure 4.1(c, g) shows diamagnetic behavior of the plasma. It is seen that neither in the broad source nor in the narrow source, expulsion of magnetic field is complete at $\beta = \left( \frac{\text{plasma pressure}}{\text{magnetic pressure}} \right)^{1}$. An expulsion for the narrow and broad source is given by Fig. 4.1(c) and Fig. 4.1(g) respectively.

An important point to note is that the discharge behavior is not controlled by the geometry of the source function of primary electrons. In fact, the discharge pattern of the two sources is indistinguishable except for the minor details. These points to the fact that spatial details of the plasma sources may be different for the two sources, but the evolution of plasma remains the same.

Figure 4.1(b, f) displays temporal variation of ion saturation current measured at the centre ($y=0, z=120\text{cm}$) by a Langmuir probe for the two plasma sources. As in discharge current plasma density grows to a saturation value in 2.5ms at $y=0$, remains nearly at a constant value (within 5%) for $\sim 4\text{ms}$ and then decays in the last 3.5ms when the arc is terminated. Figure (4.2) shows radial profile of ion saturation
Chapter 4: Characterization of ETG Plasma...

Figure 4.5: The spatio-temporal evolution of the density axially for the two plasmas. Axial distances are measured with respect to the broad source.

current corresponding to the three time scales. We notice there are no noticeable differences in these time scales for the two sources, giving the indication that plasma characteristics are independent of the nature of the source function of primary ionizing electrons.

An extension of this argument is that probably primary electrons produced by the source are, redistributed over the plasma volume through transport processes before they cause ionization in the same manner for the two cases. Consequently, plasma characteristics do not differ in any appreciable way with respect to temporal characteristics.

This is further exemplified by Fig. (4.3) wherein we have shown that even the plasma density profiles are similar in its broad characteristics. It may be emphasized here that the plasma density remains flat over about 45 cm and then falls to a value of $5 \times 10^{10} \text{cm}^{-3}$ near the wall from a value of $3 \times 10^{11} \text{cm}^{-3}$ at the plasma centre.

Having agreed that there are no major differences in the characteristics of the
In order to appreciate differences in the plasma characteristics, we have studied spatio-temporal evolution of the plasma density for the two cases.

Figure (4.4) shows radial density profile for the two cases at different times referenced with respect to initiation of arc. The profiles are markedly different for two cases in the first 0.4 ms, indicating that spatial distribution of primary ionizing electrons are controlled by the nature of the source function of primary energetic electrons. At about 0.8 ms, the two profiles appear to be similar and nearly inde-
Figure 4.7: Profiles obtained from two MFC’s, (a) narrow source shows a uniform plasma density of large scale length but a sharp temperature profile whereas (b) shows both the density and temperature having flat profiles in the case of broad source.

dependent of the nature of the source function. Density profile continues to decrease monotonically right from the plasma centre to the wall. No appreciable region of flatness can be discerned. Flat density profiles develop nearly at \( t=2.4 \) ms and continues till about \( 9.2 \) ms. The region of flatness is more expanded for narrow source function and density scale lengths are not very different \( L_b \sim 220, L_n \sim 240 \).

At about \( 9.3 \) ms, when the arc is switched off, the plasma density suffers further evolution. Between \( 9.3 \) ms and \( 10.4 \) ms, there is a clear plasma evacuation to the wall. This is indicated by peaking of plasma density away from the axis. Position of the peak seems to be shifting towards the wall. Fig. (4.5) shows spatio-temporal evolution of axial profile. It clearly shows axial transport of the plasma. The plasma is lost to the end plates.

For the studies reported here, we have chosen a time strip with the properties that plasma remains steady for the parameters of plasma density and electron temperature over the whole plasma volume. This is essential for requirement with the tools required for the analysis of fluctuations. For our experiment, \( t=6 \) ms to \( 9.2 \) ms, represents steady state.
Chapter 4: Characterization of ETG Plasma...

4.3 Gradients

It is essential that not only plasma parameters remain steady for the study of fluctuations but also the gradients. Figure (4.6) shows plasma density profiles at different instants of time. We notice that the profile fluctuates widely during the formation time, keeping region of flatness nearly constant but increasing the value of density as the discharge current increases. During the plasma decay, a similar observation is revealed, however, this time, it is entirely due to the plasma transport.

During the time period of fluctuation studies (6 - 9.2 ms), density profile remains remarkably steady for the two sources.

4.3.1 Temperature Gradient

The density and potential show no significant gradient in the core region for plasma discharge with the narrow source. However, there is significant fluctuations in plasma density in the core region. We expect that the free energy source that drives fluctuation in the core region could be in the temperature gradient. Therefore we have measured electron temperature profile in LVPD.
Chapter 4: Characterization of ETG Plasma...

Figure 4.9: Electron current-voltage profiles obtained from fast ramped Langmuir probe with narrow source. The superimposed I/V curve depicts the total spread in the electron plasma temperature estimation in the steady state region.

Figure (4.7) shows the radial profiles for both the sources. Here the temperature is obtained from the current-voltage profile from Langmuir probe by sweeping plasma for ramp voltage from -80 to 5 V. The I-V characteristics in a single plasma discharge, at each radial location are obtained to estimate the radial temperature variation. We found that the plasma produced by the broad source exhibits no gradient at the core, whereas the plasma produced from the narrow source exhibits a gradient of 1.5 eV over a radial extent of 45 cm.

A statistical error in the temperature estimate is derived from a series (n = 10) of displays in Fig. (4.8). The I-V curves, from sweep to sweep, in a single plasma discharge, points out that the drifting in the tracking of electron plasma temperature is practically not significant (~ 0.1 eV).

Also shown in Fig. (4.9) is the family of superimposed I-V plots obtained in steady state at various radial locations. This provides an overall spread (~ 1.5 eV)
Figure 4.10: A comparison of the temporal evolution of the floating potential at different radial locations. Radial distances are represented either by 'r' or by 'y'.

in the temperature radially. Since the error in $T_e$ is only $\sim 0.1$ eV, the observed gradient in the radial profiles of temperature can be assumed relevant.

### 4.4 Energetic Electrons

The temporal profiles for floating potential are shown in Fig. (4.10). It shows that the formation stage of plasma is dominated by the existence of energetic electrons ($\sim -45V$) and subsequently the floating potential profile exhibits a plateau comprising mainly of bulk electrons.

The spatio- temporal profiles, shown in Fig. (4.11) of floating potential exhibits absence of electric field in the core plasma in case of narrow source, but shows a sharp gradient in floating potential in steady state plasma in the region $r \geq 45$cm. The profiles of broad source on the other hand show a shallow profile depicting a much weak electric field. As, $\phi_p - \phi_f = 4.5 \, kT_e$ is not satisfied, the presence of
energetic electrons cannot be ruled out.

4.5 Summary

We have plasma sources with distinct characteristics mainly in the temperature profile. In broad source, we have obtained a flat temperature profile over the region where the density is flat. Even in the density gradient region, temperature profile is shallow.

In contrast we have another plasma source where electron temperature gradient is established over the region where there is no density gradient. This allows us to perform experiments in the controlled manner in the sense we can now specifically study turbulence whose origin is in the temperature gradient as in ETG, the subject matter of this thesis. However, we must report that various methods that we have tried have failed to give us a control on the scale of the temperature gradient. Pres-
ence of energetic electrons is registered and their role in the excitation of plasma turbulence needs a careful study particularly when the source for the turbulence is other than the density gradient. A detailed study on the electron temperature gradient driven high beta ETG turbulence is discussed in Chapter 5.