Density and temperature measurements of pulsed plasma produced inside a curved vacuum chamber

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Abstract. Recent experimental evidence suggests the importance of fast radial plasma transport in the scrape-off-layer (SOL) of tokamaks. The outward transport appears to be convective rather than diffusive, extends into the far SOL, and can produce significant recycling from the main-chamber walls, partially by passing the divertor. A plausible theoretical mechanism to explain this phenomenon is the radial transport of locally dense plasma created by turbulent processes. In our experiment a blob of plasma is produced using a plasma-gun and injected radially to the curved vacuum chamber. In this paper we report the measurement of electron density and temperature of the plasma blob produced by the plasma-gun inside the curved vacuum chamber using cylindrical Langmuir probes. The probes are moved both radially and transversely to flow direction. The electron density and temperature are measured ~ 10^16 m^-3 and 10^-1 eV respectively for radial flow at constant discharging potential, base pressure as well as plasma pulse time.

1. Introduction

Recent studies suggest fast radial plasma transport in the scrape-off-layer (SOL) of tokamaks. Moreover, it seems that this radial transport has not diffusive but convective like features [1]. One of the plausible mechanisms of this fast convective SOL plasma transport can be associated with plasma blobs. Recent experiments most clearly show the intermittent character of plasma turbulence in a TOKAMAK scrape-off-layer (SOL) and the importance of coherent high plasma density structures, “Blobs”, in convective cross field plasma transport [2-4]. Typical radial velocities are of the order 10^3 ms^{-1}[5,6] and typical auto-correlation times are about 20μs [7].

In the present work a washer stacked plasma gun is used to produce a blob of plasma and is injected with high speed ~ 10^4 ms^{-1}[8] into the curved vacuum chamber. Using Langmuir probe, we characterize the pulsed plasma by measuring plasma parameters. This method has the advantage that the probes are simple to make and convenient to operate as well as measurements of local plasma parameters can be done without disturbing the entire plasma [9]. Electron density and temperature are measured by biasing the probe at different distances from the plasma gun as well as at the SOL region.
2. Diagnostic and measurement principle
The work is carried out in a curved vacuum chamber made of stainless steel (SS-304) having major radius 0.4m and minor radius 0.2m. The vacuum chamber is evacuated by means of a diffusion pump coupled with a rotary pump and a low pressure (~ 0.01 mb) is maintained throughout the experiment. A blob of plasma is injected into the chamber by a washer stacked plasma gun. The gun is energized by a multistage pulse forming network (PFN) consists of capacitors (~5 μF) and inductors (~1 μH). The plasma blob interact with a DC biased cylindrical Langmuir probe and the signals are recorded on a four channel storage oscilloscope connected to the PC as shown in ‘figure 1’. From the acquired signals we measure the probe current across a resistance of 0.5 kΩ at a particular probe voltage. The radial distance of the probe from the plasma gun is varied from 0.02m to 0.16m. Probe current is measured at different bias voltages at a constant base pressure (0.01 mb), discharging potential (500V) and pulse time (35 μs).

![Figure 1. Schematic diagram of the experimental arrangement.](image)

We have measured the electron temperature from the slope of the \( \ln I_p \sim V_p \) curve using the following relation[10].

\[
\ln I_p = \left( \frac{e}{kT_e} \right) V_p + \text{constant} \tag{1}
\]

Where \( I_p \), \( V_p \), \( e \), \( k \), \( T_e \) are probe current, probe potential, electronic charge, Boltzmann constant and electron temperature respectively.

Electron density is measured using the following relation [10].

\[
n_e = \left( \frac{I_{se}}{A_p} \right) \left\{ \left( \frac{2 \pi m_e}{e^3} \right)^{1/2} \right\} \left( \frac{e}{kT_e} \right)^{1/2} \tag{2}
\]

Where \( n_e \), \( I_{se} \), \( A_p \), \( m_e \) are electron density, electron saturation current, effective area of the probe and mass of the electron respectively. \( I_{se} \) is obtained from \( V_p \sim I_p \) graph as shown in ‘figure 2’. The diameter and length of the probe are \( 7.4 \times 10^{-4} \text{m} \) and \( 1.3 \times 10^{-2} \text{m} \) respectively.

Substituting the values of \( T_e \) and \( I_{se} \) in ‘equation (2)’, electron density is obtained at different radial points inside the vacuum chamber. Variation of temperature and electron density with distance is shown in ‘figure 3’ and ‘figure 4’ respectively.
Radial profile have been obtained both for the floating potential and plasma potential as shown in ‘figure 6’ and ‘figure 7’ respectively.
3. Results and discussion
The spatial variation of electron density and temperature was observed at different distances from Plasma gun inside the curved vacuum chamber. From ‘figure 8’ it is found that the saturation current decreases with the increase in radial distance. The floating potential shifts from +5 to -7V as shown in ‘figure 6’. We conclude that the floating potential decreases with distance and becomes zero near the central region of the chamber.
The electron density decreases exponentially when the blob travels (as shown in ‘figure 3’) radially outward. The electron density reduces about 75% over a distance of 0.16m. ‘Figure 4’ shows the variation of electron temperature at different distances from Plasma gun. The temperature does not vary appreciably. The density and temperature in the present system is of the order of $10^{16}$ m$^{-3}$ and $10^4$ eV respectively as expected in technical plasma[11].

However, density and temperature increases near the central region of the chamber. We have observed that at this region the floating potential becomes zero as shown in ‘figure 6’. Our results are in good agreement with the profile of electron density, temperature and plasma potential as shown by R Barni et al [12].

4. Conclusions
The floating potential, density and temperature of a pulsed plasma propagating in a vacuum chamber is measured by single Langmuir probes as a function of distance from the plasma gun where the plasma is produced. The plasma density is $\sim 4.06 \times 10^{16}$ m$^{-3}$ at the gun mouth and it falls off rapidly in the vicinity of the gun and then gradually decreases with the increase in distance from the gun mouth. The floating potential remains positive till some distance (8 cm) from the gun mouth and then changes sign. The plasma temperature remained almost constant at all radial distances from the gun.

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