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PARTICLE AND HEAT FLUX MEASUREMENTS IN PDX EDGE PLASMAS

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PARTICLE AND HEAT FLUX MEASUREMENTS IN PDX EDGE PLASMAS

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ABSTRACT

This paper describes the use of novel combined Langmuir-calorimeter probes to measure edge plasma conditions near the midplane in PDX. The probes consisted of up to five Langmuir probes and up to two calorimeters. Single and double probe characteristics yield n_e and T_e which are compared with that derived from a triple probe analysis. The calorimeters measure heat flux in the electron and ion drift directions. This paper presents time-resolved radial profiles of n_e , T_e , V_F (floating potential), and P (heat flux) during high power neutral beam-heated, single-null discharges and circular scoop limiter discharges. The temporal dependence of these quantities displays the previously observed behavior with respect to gross discharge characteristics; however, an additional dependence on confinement mode has been observed. During the H-mode of energy confinement, a transient depression of n_e , T_e , and P occur in the scrape-off plasma.

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I. INTRODUCTION

Previously, we reported results from Langmuir probe measurements¹ and from directional calorimeter measurements² of PDX and PLT edge plasmas. In this paper, we report results from extensive measurements of edge plasmas near the midplane when PDX was operated in the single-null configuration for H-mode studies³ and in the circular scoop limiter configuration.⁴ Langmuir probe measurements were also performed in the divertor region of PDX during some of these runs.⁵

The novel combinations of calorimeter-Langmuir probes used contain up to two calorimeters to measure time-resolved heat flux in the ion and electron drift directions. Also, they contained up to five electrodes to measure floating potentials or single or double probe current-voltage $I(V)$ characteristics. The analysis of these characteristics to extract n_e and T_e used a recently published single probe model⁶ or a standard double probe model. A triple probe technique described in Sec. III gives a semi-continuous $T_e(t)$ which we compare with the double probe result.

II. PROBES AND MEASUREMENT TECHNIQUES

Six different probe head configurations were used for the measurements. Schematics of two representative versions are shown in Fig. 1. The Langmuir probes were typically 1 mm diameter Tungsten rods which protruded 2-5 mm past an insulating holder. The calorimeters were 3 mm x 8 mm Tantalum rectangles with a chromel/alumel thermocouple spot welded to their backs.

The Langmuir probes were biased with a sine wave at 30-100 Hz with peak voltages of 70-180 volts. The voltage sources were transformer isolated from the floating probes. Probe currents were measured with Pearson current monitors, and voltages were measured with purely resistive voltage dividers.

The signals were transferred to an ADC and stored for later analysis. Triple probe analysis required measuring a floating potential and voltages on both electrodes of a double probe (relative to the vacuum vessel grounding plane). For double probe analysis, the difference $V \equiv V_1 - V_2$ was used to construct the characteristic $I(V)$. The thermocouple voltage was amplified by a dc-coupled differential amplifier with a gain of 100. Details of the construction are in Ref. 7.

III. MODELS AND FITS

Stangeby's model,⁶ used to fit the single probe $I(V)$ characteristics, accounts for the strong reduction of electron collection currents in intense magnetic fields by modeling electron diffusion into the flux tube intercepting the electrode. The characteristic $I(V)$ then depends on a parameter $r \sim \sqrt{D_{\perp} D_{\parallel}}$ in addition to the usual n_e , T_e , T_i , and reference voltage (V_F or V_p). Fits of the observed $I(V)$ minimize Chi squared⁸ by adjusting these five parameters.

Examples of single probe fits are given in Fig. 2. The best fits for most of the $I(V)$ characteristics yield very small values for r (≤ 0.1). This could indicate large Z_{eff} in the edge which would make $D_{\parallel}$ small. The fit is very sensitive to the magnitude of T_e and less sensitive to the ratio $r \equiv T_i/T_e$. A considerable variation in T_i (more than a factor of two) was observed during discharges. The standard single probe model which does not account for magnetic field effects,

$$I(V) = \frac{1}{4} n_e A [-2 v_s + \bar{c}_e \exp[e(V - V_p)/kT_e]], \quad (1)$$

with $v_s = \sqrt{k(T_e + T_i)/M_i}$ and $\bar{c}_e = \sqrt{8kT_e/\pi m_e}$ disagrees strongly with the

electron collection portion of $I(V)$.

Most of the Langmuir probe results reported here are derived from double probe fits. For this we used the standard simple model,

$$I(V) = \frac{1}{2} en_e v_s A \tanh \left[\frac{eV}{2 kT_e} \right], \quad (2)$$

with A = twice the projected area of each electrode. We assumed $T_i = 3T_e$ since there are various indications that ions are hotter than electrons in edge plasmas. The double probe fits are not very sensitive to this assumption. Examples are given in Fig. 3.

The triple probe technique uses a double probe and an additional electrode a few millimeters away to measure the floating potential. A simple manipulation of Eq. (1) shows that

$$kT_e = e(V_\infty - V_f) / \ln(2), \quad (3)$$

where V_∞ is the voltage on the electron collecting electrode when the ion collecting electrode is in saturation. This permits a semi-continuous measurement of T_e which was compared to T_e as derived from the double probe method. An example of this analysis and comparison is shown in Fig. 4. T_e derived from Eq. (3) had large amplitude fluctuations which have been smoothed for Fig. 4. The double probe values for T_e agree reasonably well, showing that the triple probe method is useful for plasmas in a tokamak environment. Previous comparisons⁹ made for plasmas in weak magnetic fields have shown good agreement between the methods.

IV. PDX RESULTS

To compare edge conditions for neutral beam heated and ohmically heated plasmas, measurements for single-null discharges were made to within several cm of the outer separatrix and for scoop discharges to within 2 cm of the leading edge of the limiter.

Conditions changed abruptly at the onset of the neutral beam pulse and at the H-mode transition for diverted discharges. The shot with the triple probe analysis in Fig. 4 had an H-mode transition at 450 msec. The ion saturation current and fluctuations in the floating potential diminish abruptly. Both the electron density and temperature were reduced. The heat flux falls as well, but the time dependence of this change could not be determined since we had to average the voltage over at least 30 ms to reduce noise. Figures 5 and 6 show the time variation of n_e , T_e , and P for a discharge with an H-mode transition and for a similar discharge without a transition.

Radial profiles of edge conditions were determined for three phases of diverted discharges: an ohmic phase about 100 ms before the neutral beam pulse, an L-mode phase during the neutral beam pulse but before the H-mode transition, and an H-mode phase just after the transition, but before any edge relaxation phenomena (H_α spikes). Results from measurements of single-null operation, using a probe like that in Fig. 1a, are given in Figs. 7-11 and in the Table. The profiles for power flowing in the ion drift direction (Fig. 7) had decay lengths comparable to those observed in the past for PDX circular and inside dee discharges, but not for four null square discharges.²

Figure 8 shows the electron density profiles measured by the double probe technique. The ohmic profile is flatter than previous measurements¹ for the inner dee. The electron temperature profiles, shown in Fig. 9, are relatively flat during the ohmic and L-mode phases, and decrease faster during the H-

mode. The averaged floating potentials shown in Fig. 10 are also relatively flat.

The heat flux incident on a floating probe is predicted⁶ to be

$$P_{inc} = \frac{1}{2} n_e v_s \left(\frac{2kT_e}{1-\gamma} + 2kT_i + e\Delta V_s + \frac{1}{2} f_{fi} m_i v_D^2 \right) \quad (4)$$

where γ is the secondary electron emission coefficient, the sheath potential drop ΔV_s is a weak function of T_i/T_e , and the last term is the contribution of fast (non-thermal) ions. The absorbed or measured power P should be about $P_{inc}/2$ since about 50% of the incident ions get reflected. We can test whether T_i changes or whether fast ions contribute during neutral beam heating by plotting $2P/n_e v_s kT_e$. This ratio is given in Fig. 11. It is relatively flat, but the magnitude increases during beam heating.

We measured heat flux for circular discharges using the particle scoop limiter. Results from measurements using a probe like that in Fig 1b are shown in Fig. 12. The profiles have a steeper falloff than the single-null profiles of Fig. 7.

In conclusion, our combination probe measurements have yielded P , n_e , T_e , and V_F profiles for midplane edge plasmas. These profiles decrease slightly at the H-mode transition. The n_e profile becomes steeper during the H-mode.

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Figure Captions

- FIG. 1. Schematics of two representative probes.
- FIG. 2. Fits for single probe measurements at 191 cm: (a) 15 msec before the transition to the H-mode with $n_e = 2.7 \times 10^{12}/\text{cm}^3$, $T_e = 3.1$ eV, $T_i = 9.6$ eV, and $r = 0.08$; (b) 30 msec later with $n_e = 3.7 \times 10^{12}/\text{cm}^3$, $T_e = 4.5$ eV, $T_i = 1.3$ eV, and $r = 0.01$.
- FIG. 3. Fits for double probe measurements at 190 cm: (a) 15 msec before the H-mode transition with $n_e = 1.2 \times 10^{12}/\text{cm}^3$ and $T_e = 7.4$ eV, (b) 15 msec after with $n_e = 4.6 \times 10^{11}/\text{cm}^3$ and $T_e = 6.6$ eV.
- FIG. 4. Comparison of double and triple probe measurements of T_e for the same shot used in Fig. 3: Double probe voltages V_1 , V_2 , $V_1 - V_2$, and

current I ; V_F and triple probe kT_e both averaged over 1 msec; $\bullet$ kT_e from double probe $I(V)$ fits.

FIG. 5. Time variation of n_e , and T_e for similar discharges with and without an H-mode transition.

FIG. 6. Time variation of P for similar discharges with and without an H-mode transition.

FIG. 7. Power profiles for the ohmic phase O, the L-mode X, and the H-mode Δ measured with the probe shown in Fig. 1a for single-null discharges with an inner separatrix at 182 ± 1 cm and an outer separatrix at 186 ± 1 cm.

FIG. 8. Density profiles as in Fig. 7.

FIG. 9. Electron temperature profiles as in Fig. 7.

FIG. 10. Floating potential profiles as in Fig. 7.

FIG. 11. Ratio of heat flux to particle flux times electron temperature.

FIG. 12. Power profiles for circular scoop-limited plasmas during the ohmic phase O and the neutral beam phase Δ measured with the probe shown in Fig. 1b. The limiter blade extends between 193 and 195 cm. The scoop entrance extends between 195 and 197 cm.

TABLE

INVERSE SLOPES AND LINEAR-CORRELATION COEFFICIENT
SQUARED FOR THE FITS IN FIGURES 7-11

	MODE	λ	R^2
P	H	2.9 cm	0.59
	L	3.8	0.87
	OH	-8.3	0.18
n_e	H	7.1	0.44
	L	5.3	0.86
	OH	5.6	0.86
T_e	H	3.8	0.42
	L	11.0	0.15
	OH	-47.6	0.02
V_F	H	27.0	0.87
	L	40.0	0.93
	OH	5.0	0.78
$\frac{2P}{n_e V_s k T_e}$	H	0.42	0.10
	L	0.59	0.13
	OH	1.32	0.49

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PLAN VIEW

ELEVATION VIEW

FIGURE 1

#83P0252

FIGURE 2

#83P0246

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

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