Measurement of edge ion temperature in W7-X with island divertor by a retarding field analyzer probe

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1. Abstract

The Ti edge profile has been successfully measured at W7-X in an island divertor configuration using a retarding field analyzer (RFA) probe on a reciprocating manipulator. The experimental observations show that in the standard configuration, an ion temperature shoulder at the plasma boundary has been observed near the location where a sudden change of the magnetic field connection length appears in the scrape-off layer (SOL) region. In addition, the edge ion-to-electron temperature ratio has been calculated which gradually increases with the major radius and decreases with the normalized ion collisionality.

Experimental setup

A retarding field analyzer probe has been mounted onto the MPM shaft [1] to measure the W7-X edge plasma profiles (as seen in figure 1). The RFA probe is designed based on a prototype first tested on EAST [2]. The probe is shaped to adapt to the magnetic geometry such that the entrance slits are oriented poloidally along a flux surface. The probe consists of two identical analyzers mounted back to back. For each side, the RFA components consist of a front plate with 3 entrance orifices (width 300 μm, length 8 mm per orifice), a thin plate with 3 entrance slits (width 30 μm, length 8 mm per slit and thickness 50 μm) on the front plate, three successive grids, and three collector plates. Besides the RFA components, there are also five Langmuir tips

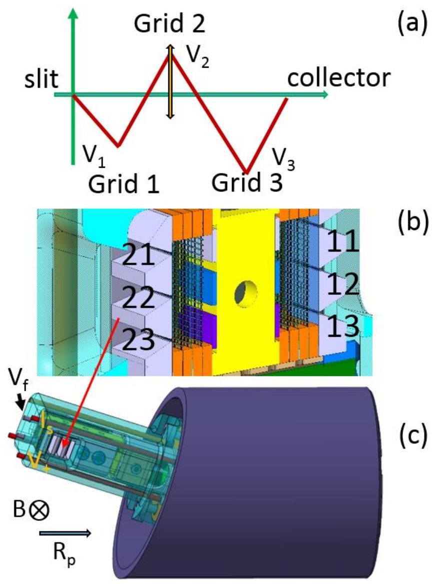

Figure 1. (a) biasing voltage scheme; (b) zoomed in RFA cavity; (c) the RFA probe head drawing

arranged at the RFA probe top. Three of the total five tips were used as a triple probe in OP1.2b to provide the plasma information of floating potential, potential measured by positive probe and ion saturated current.

In the experiments reported here, an identical positive dc current was applied to all 10 control

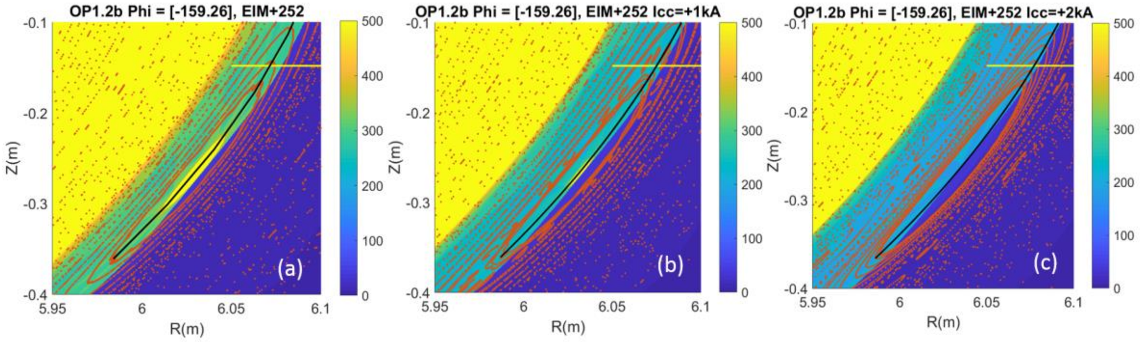

Figure 2. Connection lengths profiles and superimposed standard configuration Poincaré plots of different control coil cases: (a) Icc=0 kA; (b) Icc=1 kA; and (c) Icc=2 kA. The yellow line is the RFA channel 23 measurement path. The black curve connects the island O point and X point.

coils. This results in both an increase of the island size as well as a decrease of the connection length. The Poincare plot and the connection length distribution affected by the control coils have been calculated with the field line tracing web service [3]. The magnetic field generated by 10 control coils is superimposed into the ideal standard configuration to consider the control coil effect. For simplicity, only the case without plasma current is considered. The result is illustrated in figure 2, which shows 2D connection length plots in the R-Z plane of the MPM (color coded), a Poincare plot (red dots) and the path of the RFA (yellow line) for different control coil currents. To guide the eye, a black curve connecting to islands O and X point is added. The area of infinity connection length (marked in yellow) to the left of the edge island structure indicated by the Poincare plot is the confined area. As seen in figure 2(a), due to the island geometry, an infinity connection length region is formed at the island remnant region. With increasing the control coil current Icc, the edge island is enlarged, and interacts more efficiently with the divertor plate. As a consequence, the 2D connection length distribution would be modified, including shifting the separatrix inward and shrinking the infinity connection length region near the island O point.

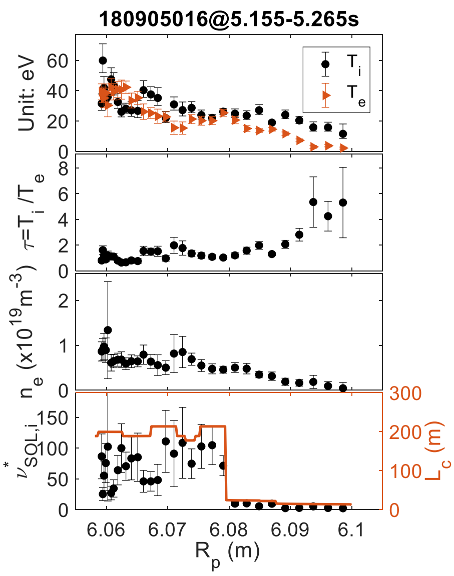

Figure 3. Radial profiles of (a) Ti and Te; (b) ion to electron temperature ratio $\tau_{i/e}$; (c) ne and (d) normalized ion collisionality in SOL $\nu^*_{SOL,i}$ for discharge #180905016 with covered Lc profile for Icc=2kA.

A typical set of plasma edge profiles measured by RFA is shown in Fig. (3). In this discharge #180905016, the injected ECRH heating power is 5 MW and the central line integrated plasma density is $9\times10^{19}m^{-2}$. The edge island configuration has been expanded by the control coils (Icc=2kA). As shown in figure 3, the plasma parameter profiles (Ti, Te and ne) approximately decrease with the major radius and are flat in the intermediate connection length region. The ion to electron temperature ratio $\tau_{i/e}$ profile shown in figure 3(b) gradually increases with the major radius. While the island geometry seems flattening the $\tau_{i/e}$ profile since the $\tau_{i/e}$ increment inside the intermediate region is much small than the one in the short connection length (Lc~10m) region. The normalized ion collisionality in SOL $\nu^*_{SOL,i} \equiv L_c/\lambda_{ii} \approx 10^{-16} n_u L_c/T^2_{iu}$ profile shown in figure 3(b) is roughly varied between 20 and 100. This $\nu^*_{SOL,i}$ value indicates that the SOL plasma transport is within the conduction-limited regime for the tokamak case.

Since the above plasma parameter dependence of Ti and $\tau_{i/e}$ imply that the collisionality is probably correlated with the ion temperature, the collisionality dependence of ion temperature and ion to electron temperature is studied. In figure 4, the plasma parameters Ti, Te, ne and $\tau_{i/e}$ measured by the RFA probe are plotted as a function of the normalized ion collisionality $\nu^*_{SOL,i}$ As can be seen, the ion temperature gradually decreases with $\nu^*_{SOL,i}$, while the electron temperature and density are dispersed and seem independent on $\nu^*_{SOL,i}$. Increasing the control coil currents would expend the island geometry, which overall reduces the ion temperature, electron temperature and density. $\tau_{i/e}$ is observed to be gradually decreased with $\nu^*_{SOL,i}$ from ~2 to ~1 when the normalized ion collisionality increases from ~10 to ~200. This evolution seems independent on different control coil current conditions even though the parameters (Ti, Te, ne and Lc) has been changed by expending the island geometry. This may imply that slightly tailoring the island configuration would not significantly change the ion and electron energy balance. The relation of $\tau_{i/e}$ with $\nu^*_{SOL,i}$ for the measurement region approximately follows the formula $\tau_{i/e} = 8 \times \nu^{*-0.5}_{SOL,i}$ which is plotted as a solid red line in

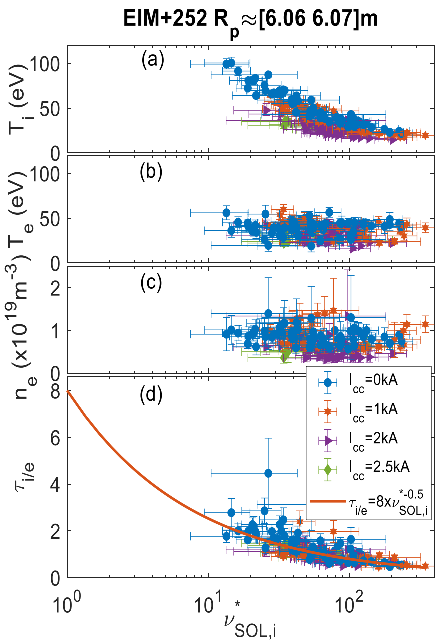

Figure 4. RFA measurement for (a) Ti, (b) Te, (c) ne and (d) $\tau_{i/e}$ as a function of the normalized ion collisionality $\nu^*_{SOL,i}$. The solid line obeying the formula $\tau_{i/e} = 8 \times \nu^{*-0.5}_{SOL,i}$ is used to

figure 14(d) to aid the eye. This trend is similar to the simulation results for tokamak configuration using the EDGE2D code and an 'onion-skin method' as shown in chapter 4 of the book [4]. Comparing with the tokamak case, $\tau_{i/e}$ obtained by the RFA experiment in Tore Supra plasma with Ohmic heating indicates that $\tau_{i/e}$ first increases with $\nu^*_{SOL,i}$, and then gradually decreases with $\nu^*_{SOL,i}$. This may imply that the dependence of $\tau_{i/e}$ on $\nu^*_{SOL,i}$ in stellarator may be also not monotonically decreasing, but could increase in low $\nu^*_{SOL,i}$ region of [1 10].

2. Summary

In this work, the ion temperature profile at the plasma boundary has been measured on W7-X by a retarding field analyzer (RFA) probe. The experiments are limited to high density regime to minimize the flow effect on the ion temperature in single side. The experimental observations show an ion temperature shoulder near the location where a sudden change of the magnetic field connection length appears in the edge island. The edge ion-to-electron temperature ratio $\tau_{i/e}$ has been obtained by RFA probe. The results show that the ion temperature gradually decreases with the ion collisionality $\nu^*_{SOL,i}$. Increasing the control coil currents would expend the island geometry, which in general reduce the ion temperature, electron temperature and density. $\tau_{i/e}$ has been found to be gradually decreased with $\nu^*_{SOL,i}$ from ~2 to ~1 when the normalized ion collisionality increases from ~10 to ~200. This evolution seems independent on the control coil current conditions even though the plasma parameters and island configuration have been changed.

3. References

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