Far SOL Transport and Main Wall Plasma Interaction in DIII-D* EX-D

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Plasma interaction with the main chamber wall is of critical importance for the next step fusion devices such as ITER. We report studies of the far scrape-off-layer (SOL) and near-wall plasma parameters, cross-field transport, and main wall plasma interaction in DIII-D. SOL plasma parameters depend strongly on the configuration and confinement regime. In L-mode cross-field transport increases with the average discharge density and elevates the far SOL density, thus increasing plasma-wall contact. In H-mode between edge localized modes (ELMs), plasma-wall contact is generally weaker than in L-mode. During ELMs plasma fluxes to the wall increase to, or above the L-mode levels. Depending on the discharge conditions ELMs are responsible for 30%-90% of the total plasma fluxes to the main chamber wall. Cross-field fluxes in far SOL are dominated by large amplitude intermittent transport events that may propagate all the way to the outer wall and cause sputtering. Assessment of the main wall erosion due to intermittent events and ELMs may impact the choice of the first wall material and design for ITER.

Figure 1 shows SOL profiles (versus the distance from the LCFS) of the density, density root-mean-square fluctuation level, and temperature obtained by the midplane reciprocating probe in three lower single null (LSN) discharges, a low-density L-mode ($n/n_{Gw} \sim 0.36$), a high density L-mode ($n/n_{Gw} \sim 0.58$), and a moderate density H-mode ($n/n_{Gw} \sim 0.65$). In the high density L-mode the SOL density profile is very broad and extends all the way to the outer wall. The density and the density fluctuation amplitude in the low density L-mode are lower throughout the SOL by a factor of 2-3 than the corresponding high density L-mode values. In the H-mode discharge between ELMs the SOL density and temperature are below the L-mode values. During ELMs density, temperature and fluctuation amplitude in the far SOL increase to the highest L-mode levels, thus manifesting a comparable level of the plasma-wall contact.

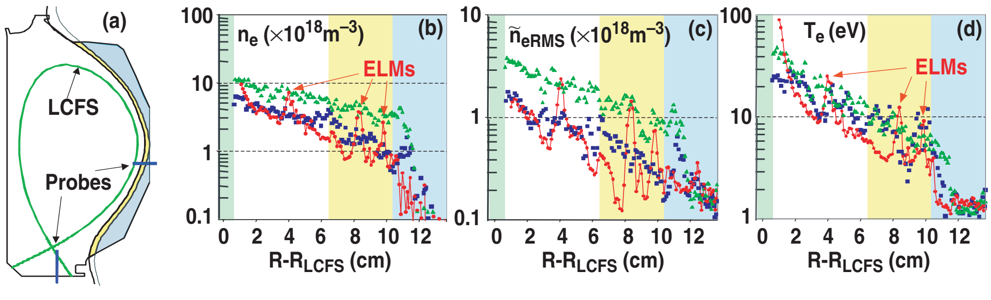

Fig. 1. Schematic of the DIII-D outer SOL (a); SOL profiles of electron density (b), density RMS fluctuation level (c), and electron temperature (d) in low-density L-mode (blue), high density L-mode (green), and a moderate density H-mode (red). Shading in (b-d) corresponds to the SOL regions of the same color in (a)

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The magnitude of the total plasma ion flux to the low field side (LFS) of the main wall can be estimated by applying a "window-frame" analysis technique to the part of the SOL limited by the upper and lower divertor baffle structures (yellow region in Fig. 1(a)). Depending on the discharge density and confinement regime, the estimated ratio of the LFS wall ion flux to the ion flux into the divertor changes from 0.25 to about 1. This estimate is in reasonable agreement with UEDGE modeling.

As reported earlier in ASDEX, C-Mod, DIII-D, JET, and other machines, fluctuations of electron density and temperature feature large amplitude intermittent events. Those events are thought to be due to coherent plasma structures (blobs) that are formed at or near the LCFS and propagate outwards through the SOL. In low density L-mode and between ELMs in H-mode the blobs thermalize with the background plasma and decay before they reach the outer wall. In high density L-mode and during ELMs in H-mode intermittent events get to the wall and may cause sputtering. The intermittency has a qualitatively similar character in L-mode and H-mode both between and during ELMs. An ELM propagating through the far SOL often appears as a series of intermittent events comparable in duration and amplitude to those observed in L-mode. This is illustrated in Fig. 2 showing a time series of the plasma density and temperature in the far SOL derived from the mid-plane probe data in high density L-mode and ELMing H-mode. The probe is moving, so both time and space scales are shown. In both cases intermittent events are observed on the field lines terminating on the main wall elements, thus signifying substantial plasma-wall contact and possible erosion.

Outward expansion of the density profile and transient increase of the near-wall plasma density during ELMs was observed by the fast profile reflectometer located at the outer mid-plane. The observed radial propagation velocity of the ELM density pulse, about 500 m/s, is consistent with the E×B velocity measured by the midplane probe array.

A relative contribution of ELMs to the total ion flux to the outer wall can be estimated from the probe data. This contribution varies from about 30% to 90% depending on the discharge conditions, ELM size and repetition frequency. At the highest densities ($n/n_{Gw} \sim 1$) the relative ELM contribution to the wall fluxes tends to decrease due to increased plasma-wall contact between ELMs and reduced ELM amplitude.

The midplane reciprocating probe in a stationary mode was used to monitor the near-wall plasma conditions during disruptions. Transient bursts of the plasma density up to 2×10^{18} m^{-3} and temperature in excess of 100 eV were observed well within the outer wall shadow.

DIII-D features three toroidally localized “bumper limiters” on the outer wall. Analysis of the reciprocating probe data shows that the limiters affect SOL plasma parameters only in the regions directly connected to them by the magnetic field lines. Therefore, toroidally localized limiters are not able to protect the whole outer wall from the plasma contact.

Increasing the distance between the LCFS and the outer wall (outer gap) in otherwise similar LSN L-mode shots was shown to reduce the outer wall plasma contact. An increase of the outer gap from 8 to 10 cm reduced the near-wall midplane density by a factor of 2-3.

Plasma conditions in the lower divertor in an upper single-null (USN) configuration are comparable to those near the outer wall. A Divertor Material Evaluation System (DiMES) probe containing samples of several ITER-relevant materials (including Be and W) was exposed to a series of USN L-mode discharges as a proxy to measure the first wall erosion.

In summary, we present experimental evidence of significant main wall plasma contact in DIII-D. High particle and heat fluxes to the main wall, particularly during ELMs and disruptions can lead to unacceptably high loads and damage of the first wall in the next step fusion devices. Suitable first wall materials and adequate outer wall gaps have to be used.

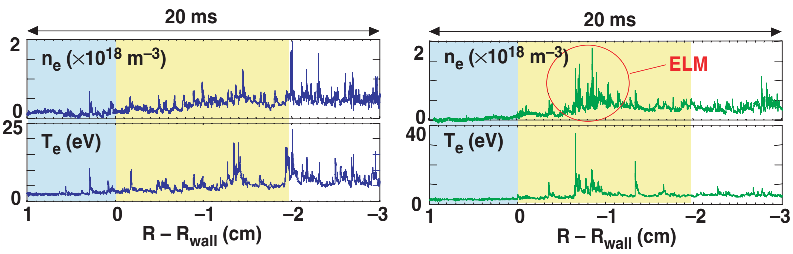

Fig. 2. Time series of the far SOL plasma density and temperature in high-density L-mode (blue) and ELMing H-mode (green). Shading convention is the same as in Fig. 1.