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Investigation of spatially resolved Hα spectral line profiles observed in LHD divertor region

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1. Introduction

In fusion devices, the spatial distribution of neutral hydrogen atoms is strongly influenced by the ion flux distribution on the plasma facing components. The Large Helical Device (LHD) [1] is a heliotron-type device, and the ion flux distribution on the divertor is non-uniform in both toroidal and poloidal directions [2]. The distribution varies significantly with the edge magnetic field lines structure, and thus with the operational magnetic configuration such as the position of the magnetic axis R_{ax}. In order to investigate the generation processes and the behavior of the hydrogen atoms in LHD, the spatially resolved Hα spectral line profile measurement observing the inboard divertor region has been performed. In this study, the relation between the spatial distribution of Hα emissions and the distribution of the ion flux on the divertor is discussed for a inward shifted R_{ax} configuration in which the ion flux is much intensive in the inboard divertor.

2. Experimental setup

LHD is an l=2/m=10 heliotron device with the intrinsic helical divertor structure [3,4], where l and m are the polar number and the toroidal period number, respectively. The Hα emissions at the inboard edge/divertor region have been measured by an echelle grating spectrometer [5,6]. In order to acquire the spatial distribution of the emissions, a 2−dimensional optical fiber array equipped with 30 fibers (a grid of 3×10) is employed. The measurement has been performed with the selected seven sight lines out of 30. The array can be axially rotated around the center of the viewing field so as to adjust the observation area. Figure 1 shows the actual spot positions of the sight lines (the red circles with the labelling of SL1~7) for the observation of

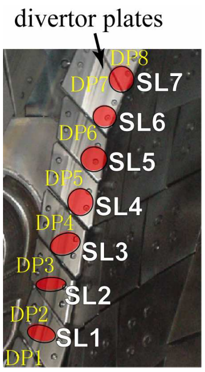

Figure 1. Spot positions of sight lines for observation of inboard divertor region.

the inboard divertor region. The divertor plates in the viewing field are labelled as shown in the figure as DP1~DP8. The emissions are transferred via 200 μm core quartz optical fibers to the entrance slit of the spectrometer, and then the diffracted light is detected by a 1024×512 pixels CCD (Charge Coupled Device) camera (Princeton Instruments, TE/CCD−1024SB). The pixel size of the CCD camera is 24 μm square and the reciprocal linear dispersion at around 656 nm is 0.0024 nm/pixel (0.1 nm/mm). The minimum time resolution of the measurement is 200 ms.

3. Experimental results and discussions

3.1. Influence of the edge magnetic field structure on the $\bar{n}_e$ dependence of Hα line intensity

The observed Hα spectral line profiles can be decomposed into two Gaussian components of the narrow and the broad shapes. The narrow components which have a typical Doppler width of ~3 eV represent the emission of the dissociated atoms. The broad components of several tens of eV can be ascribed to the charge-exchanged or reflected atoms [7,8].

Figure 2 show the footprint of the divertor field lines which have connection lengths of over 30 m on the inboard divertor plates (a), the particle deposition profiles calculated by means of EMC3−EIRENE code (b) and Poincaré plots of the field lines on the observed cross-section (c) for the inward shifted magnetic configuration of R_{ax} = 3.60 m. DPA in the figure designates the divertor probe array installed in the edge of DP2 (shown by the green line). The green rectangle in Fig. 2(b) represents the observed area. The footprints with longer connection length are localized on DP2 which is viewed by SL1. Other divertor plates (DP3~DP8) have scarce footprints, however, the calculation results of the particle deposition profile show DP3~DP5 also have particle loads. Mainly in the vicinity of these plates (DP2~DP5), the hydrogen atoms is considered to be generated. In Fig. 2(c), the dots around the LCFS (Last Closed Flux Surface) show the open field lines. As shown in Fig. 2(c), the plasma along the divertor leg

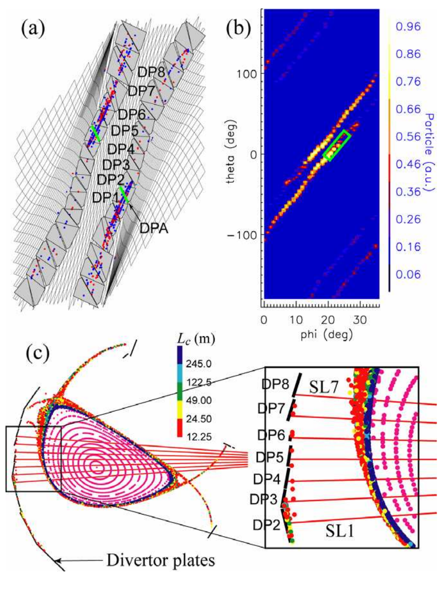

Figure 2. (a) Footprint of divertor field lines on the inboard divertor. The blue dots indicate the field lines with long connection length (L_c > 250 m). (b) Particle deposition profile calculated with EMC3-EIRENE and (c) Poincaré plots of the field lines on observed cross-section.

exists in the vicinity of the divertor plates DP2~DP7. The upper sight lines in the figure have the narrower gap between the divertor plates and the edge plasma region, and also have the thicker edge plasma region compared to that in the lower sight lines.

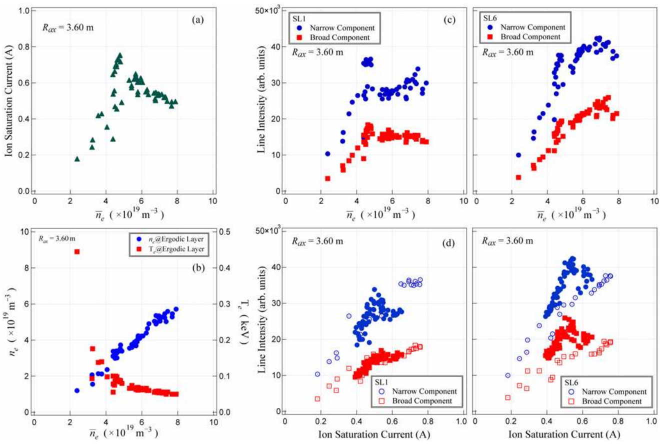

Figure 3. $\overline{n}_e$ dependences of (a) ion saturation current, (b) n_e and T_e of edge plasma region and (c) line intensities at SL1 and SL6. (d) Line intensities are also plotted against ion saturation current.

Figure 3 show the $\overline{n}_e$ dependences of the ion saturation current I_{is} measured by the divertor probe array (a), n_e and T_e of the edge plasma region (b), the line intensities of the narrow and the broad components of Hα at SL1 and SL6 (c) and the line intensities are also plotted against I_{is} (d). The open and the filled symbols in Fig. 3(d) correspond to $\overline{n}_e < 5.0\times10^{19}$ m^{-3} and $\overline{n}_e > 5.0\times10^{19}$ m^{-3}, respectively. As shown in Fig. 3(a), I_{is} increases with $\overline{n}_e$ and the rollover occurs at $\overline{n}_e \sim 5.0\times10^{19}$ m^{-3}. The $\overline{n}_e$ dependences of the line intensities at SL1 are clearly influenced by the divertor flux as shown in Fig. 3(c), though the line intensities still linearly increase with $\overline{n}_e$ for $\overline{n}_e > 5.0\times10^{19}$ m^{-3} at SL6. As shown in Fig. 3(d), the line intensities are almost proportional to I_{is} at SL1 for the entire range of measured $\overline{n}_e$. This result suggests that the Hα emissions observed at SL1 are mainly from the hydrogen atoms which are recycled on the divertor plate. At SL6 for $\overline{n}_e > 5.0\times10^{19}$ m^{-3}, however, the line intensities are not proportional to I_{is} and tend to be higher than those for $\overline{n}_e < 5.0\times10^{19}$ m^{-3}, despite that the amount of the hydrogen recycling in divertor region is considered to be decreased due to the rollover of the divertor flux. A possible explanation for this is that the Hα emissions do not depend on the amount of the hydrogen recycling in the divertor region but the edge electron density as implied by the continuous increase of the edge n_e shown in Fig. 3(b). These observations suggest the following: the plasma along the divertor leg partially detaches at the vicinity of DP2 for $\overline{n}_e > 5.0\times10^{19}$ m^{-3}, while the plasma along the divertor leg is thought to be remained at around this high density operation and the Hα line intensities tend to depend on the increase of the edge n_e.

3.2. Flushing Ion flux in pellet fuelling discharge

Figure 4 shows the time evolution of plasma parameters in a pellet fuelling discharge in the R_{ax} = 3.60 m configuration. Three fuelling pellets are injected at 0.95, 1.05 and 1.15 s. At the 1st pellet injection, the ion saturation current does not show significant change, while the significant increases are observed at the following pellet injections. The pellets successfully raise the core density [9], however, the 2nd and 3rd pellets increase the flushing ion flux toward the inboard divertor. The line intensities of the narrow component for each sight line have their peaks at different timing. At SL1 and SL2, the peak comes at ~1.1 s, and it is earlier than SL3~SL7. This peak timing agrees with the significant increase of the I_{is}. In the observed region, the ion flux is concentrated at DP2 where the edge magnetic field lines are thickly connected and enhance the neutral hydrogen recycling there.

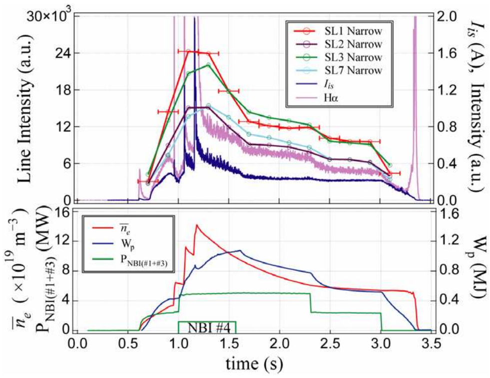

Figure 4. Time evolutions of line intensity of narrow component for several sight lines, the ion saturation current, line-averaged density, stored energy and the injected power with NB in a R_{ax}=3.6m configuration with pellet injections.

4. Summary

In the inward shifted configuration of R_{ax} = 3.60 m, the footprints of field lines with the connection length of over 30 m are localized at one of the divertor plates in the observed area. The $\overline{n}_e$ dependence and the signal peak in the pellet fuelling discharge of the Hα line intensities at the sight line which views this divertor plate are clearly affected by the divertor flux. At the other sight lines, the plasma along the divertor leg and the edge plasma region may contribute the Hα emissions for the partial detachment regime. These results seem to be consistent with the edge magnetic field structure in the observed region.

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