Correlation study between two-dimensional impurity distribution and edge magnetic structure in Large Helical Device

H. M. Zhang[1], S. Morita[1,2], T. Ohishi[1,2], X. L. Huang[1], Y. Narushima[1,2], M. Goto[1,2] and M. Kobayashi[1,2]

[1] *Dept. of Fusion Sci., Graduate University for Advanced Studies, Toki 509-5292, Gifu, Japan*

[2] *National Institute for Fusion Science, Toki 509-5292, Gifu, Japan*

1. Introduction

The transport in edge plasmas can be controlled in both the tokamak and helical devices, when the resonant magnetic perturbation (RMP) is applied. In tokamaks, the RMP is mainly used to mitigate the edge-localized mode (ELM) [1]. In the Large Helical Device (LHD), on the other hand, edge magnetic island (m/n=1/1) formed by the RMP is used to sustain a steady state detached plasma without impurity gas puff [2]. It means that the edge impurity transport can be changed by the RMP. In a previous study [3], it is found that the RMP changes the impurity screening effect in the ergodic layer as a result of data analysis on the impurity emission in extreme ultraviolet (EUV) and vacuum ultraviolet (VUV) ranges. However, any impurity profile analysis has not been done until now. Recently, space-resolved EUV spectrometers have been developed in LHD to measure a vertical profile and 2-D distribution of the impurity line emission [4,5]. In the present study, the vertical profile and 2-D distribution of the impurity line emission in the EUV wavelength range are analyzed to investigate the effect of the m/n=1/1 magnetic island formed by the RMP on the edge impurity transport.

2. Experimental setup

In LHD, the m/n=1/1 magnetic island formed by the RMP coil system was originally used in the local island divertor experiment to realize an efficient particle exhaust. The O-point of the m/n=1/1 magnetic island is formed at the outboard side of horizontally elongated plasma cross section in #6-O (ϕ=180°) or #7-O (ϕ=216°) toroidal location, of which the configuration is called 6-O or 7-O island, respectively. Since the magnetic axis (R_{ax}) is set to 3.75 m in the present study, the radial location of the m/n=1/1 island is located just inside of the last closed flux surface (LCFS). The edge magnetic field structure with RMP is temporally kept constant during the discharge in LHD.

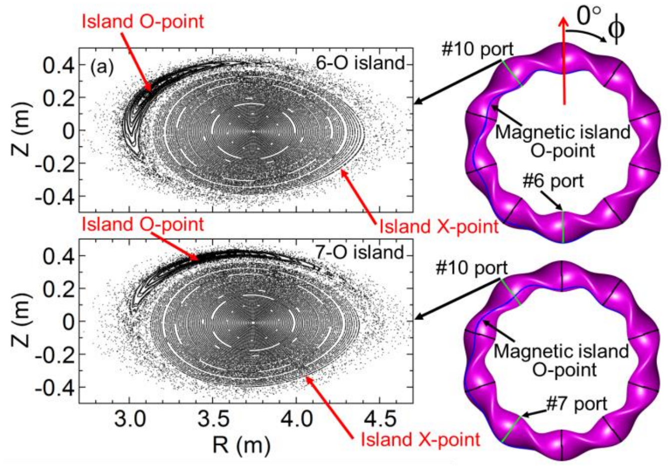

Fig.1 Poincare plot of flux surface in vacuum condition at #10-O toroidal location for (a) 6-O and (b) 7-O islands.

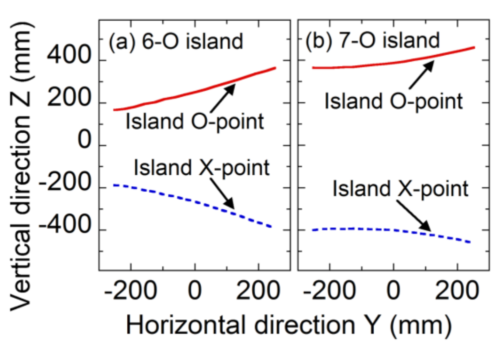

Fig.2 Vertical position of island O-point (solid line) and X-point (dash line) of the m/n=1/1 magnetic island within the observation area of EUV_Long2 spectrometer installed at #10-O LHD port for (a) 6-O and (b) 7-O islands, respectively.

The EUV spectroscopies are installed at the #10-O LHD port (ϕ=324°). Two EUV spectrometers named EUV_Short and EUV_Long are always used to monitor the impurity behavior of LHD discharges by measuring the impurity line emission in wide wavelength ranges of 10–130 and 30–650 Å, respectively [6]. Another two space-resolved EUV spectrometers named EUV_Short2 and EUV_Long2 measure the vertical profile and 2-D distribution of impurity line emissions, respectively [4,5]. As shown in Fig. 1, the local O-point of m/n=1/1 island at #10-O LHD port is localized at the inboard side for both the configurations of 6-O and 7-O islands. The 2-D observation area of the EUV_Long2 spectrometer (500≤Z≤500mm and -250≤Y≤250mm) and the position of island O- and X-points are shown in Fig.2. The vertical position of the magnetic island O-point at 7-O island moves a larger distance (Y=165-365mm) compared to 6-O island (Y=365-460mm).

3. Experimental results and discussion

Radial profiles of electron density and temperature are shown in Figs.3 (a), (b) and (c) for normal discharges without RMP, 6-O and 7-O islands, respectively. A flattening of the T_e profile is clearly seen at $\iota/2\pi=1$ reflecting the presence of magnetic island for both 6-O and 7-O island cases. The width of the local flattening shape of the T_e profile reflects the size of the magnetic island.

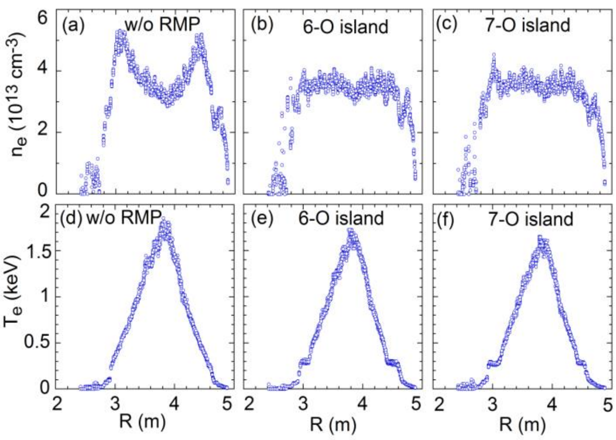

Fig.3 Radial profiles of n_e and T_e in discharges without RMP, with 6-O island and with 7-O island.

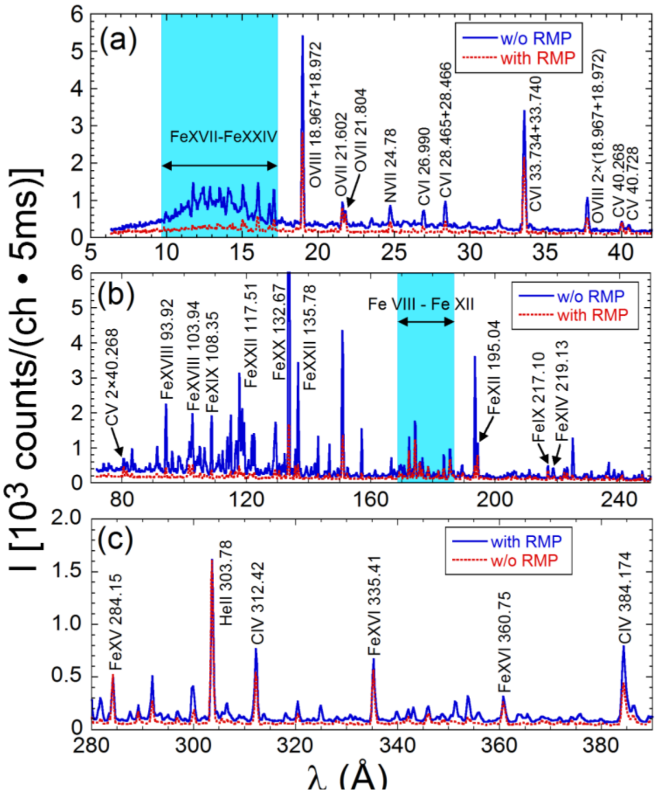

Fig.4 EUV spectra of impurity emissions from discharges without RMP (solid line) and with RMP (dotted line).

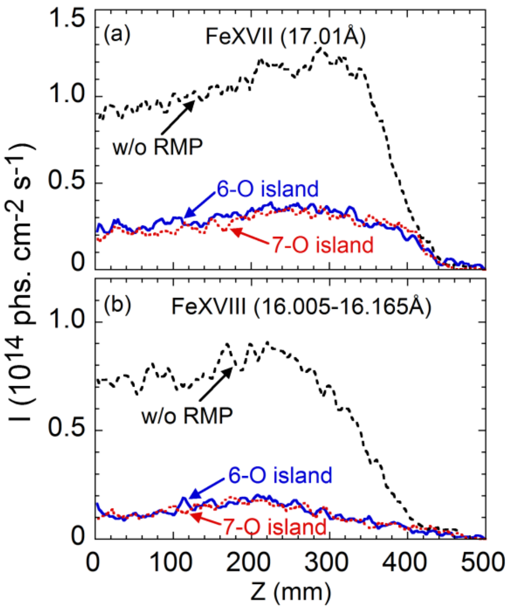

Fig.5 Vertical profiles of (a) FeXVII and (b) FeXVIII in discharges without RMP (dashed line), with 6-O island (solid line) and with 7-O island (dotted line).

Impurity spectra are compared between discharges with and without island in wider wavelength range, as shown in Figs. 4 (a), (b) and (c). It is very clear that emissions from highly ionized iron at plasma core, e.g. FeXVII–FeXXII at 10-17Å, significantly decrease when the RMP is applied. Both the 6-O and 7-O island cases indicate the same result. On the other hand, emissions from low-ionized iron at plasma edge, e.g. FeVIII–FeXII at 170-177Å show very little change. The same result is also observed in in the vertical profile of FeXVII and FeXVIII, as shown in Figs. 5 (a) and (b), respectively. This large emission change in the plasma core cannot be explained by a small change in T_e and n_e profiles. Therefore, the result strongly suggests that the presence of the m/n=1/1 magnetic island prevents the transport of iron ions from the ergodic layer to the plasma core.

The effect of RMP is also clearly seen in the 2-D distribution of FeXVI emission. The result is shown in Fig.6. In the case of 6-O island in Fig.6 (b), the FeXVI emission indicates a up/down asymmetry, while the emission from the case without island in Fig.6 (a) shows almost uniform intensity. The up/down asymmetry becomes more remarkable in the 7-O island case. In addition, the emission is stronger at the right hand side than that at the left side. When the 2-D FeXVI distribution is compared between Figs. 6 (b) and (c), the vertical position of island O-point shown in Figs. 2 (a) and (b) has to be considered. It is then understood that the FeXVI emission can be enhanced near the island O-point. In contrast to this, the 2-D distribution of CIV emission has no significant change among the three cases, as shown in Figs. 7(a), (b) and (c). The reason is very clear because the CIV is located in the ergodic layer outside LCFS where the effect of RMP is basically absent. We then conclude the m/n=1/1 magnetic island formed just inside LCFS does not give any obvious effect to the impurity transport in the ergodic layer.

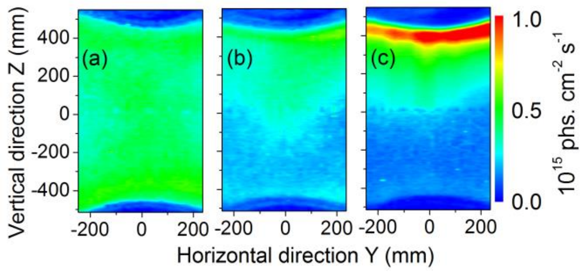

Fig.6, 2-D distributions of FeXVI in discharges (a) without RMP, (b) with 6-O island and (c) with 7-O island.

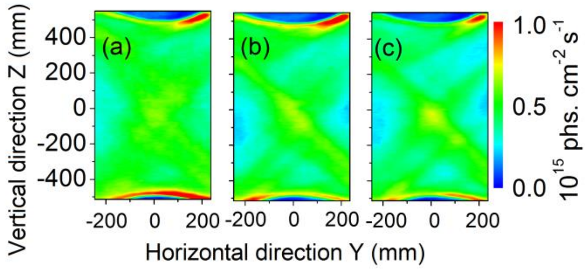

Fig.7, 2-D distributions of CIV in discharges (a) without RMP, (b) with 6-O island and (c) with 7-O island.

4. Summary

When the RMP is applied, iron emissions from plasma core significantly decrease, whereas iron emissions from plasma edge do not change. It indicates that the m/n=1/1 magnetic island can prevent the impurity transport from the plasma edge to plasma core. It is also found that the FeXVI emission is selectively enhanced near the O-point of the island showing an extremely large up/down asymmetry.

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