§3. Observation of Carbon Impurity Flow in the Ergodic Layer of LHD and its Impact on the Edge Impurity Control

Oishi, T., Morita, S., Dai, S.Y., Kobayashi, M., Kawamura, G., Huang, X.L., Zhang, H.M., Liu, Y., Goto, M.

Stochastization of edge magnetic fields has been extensively studied not only for the ELM mitigation but also for the plasma detachment and the impurity transport. Large Helical Device (LHD) has a thick stochastic magnetic field layer called “ergodic layer” located at the edge plasma with three-dimensional structure intrinsically formed by helical coils. Recently, reduction of the parallel impurity transport, so called “impurity screening”, has been studied in LHD. The theoretical modelling explains that the parallel momentum balance on impurity ions in the ergodic layer determines the direction and quantity of the impurity flow, which can be the key mechanism driving the impurity screening. Therefore, precise profile measurements of the impurity flow are required to examine the validity of the theoretical modelling on the impurity transport in stochastic magnetic field layer.

Space-resolved VUV spectroscopy using a 3 m normal incidence spectrometer has been developed to measure the impurity emission profile in a wavelength range of 300 - 3200 Å[1]. The VUV spectrometer was installed on a horizontal diagnostic port (#10-O). Figure 1 illustrates an observation range of the VUV spectroscopy and edge magnetic fields with magnetic axis R_{ax} = 3.6 m and the toroidal magnetic field B_t = 2.75 T. The emission intensity, the ion temperature, the impurity ion flow, and their vertical profiles at a horizontally-elongated plasma position of LHD are derived by measuring the Doppler profile of impurity line spectra.

Figure 2 shows a full vertical profile of C^{3+} impurity flow is evaluated from Doppler shift of the second order of CIV line emission (2 × 1548.20 Å) for a hydrogen discharge with n_e = 6.0 × 10^{13} cm^{-3} and P_{in} = 10 MW. The horizontal axis, Z (mm), is the vertical position of observation chords at R = 3600 mm. The measured flow velocity in Fig. 2 is projection of the flow along the observation chord which can be approximately considered to be the direction of the plasma major radius. It is found that the carbon flow at the top and bottom edges in the ergodic layer has the same direction toward outboard side along the major radius direction. The simulation result of C^{3+} impurity flow parallel to the magnetic field lines calculated with a three-dimensional simulation code, EMC3-EIRENE is also plotted with a dashed line in Fig. 2. It indicates that the major radius component of the flow has the same direction toward outboard side at the top and bottom edges in the ergodic layer. The experiment and the simulation agree with each other quantitatively, which concludes that the parallel flow in the ergodic layer can be well explained by the presently used theoretical modelling.

Figure 3 shows the observed C^{3+} flow at the top and bottom edges of the ergodic layer as a function of density. The flow velocity increases with the density at both the top and bottom edges of the ergodic layer. The EMC3-EIRINE simulation predicts that a friction force between bulk ions and impurity ions becomes dominant in the parallel impurity momentum balance in the ergodic layer when the electron density increases[2]. The density dependence of the flow in the modelling can be also clarified by the experimental result.

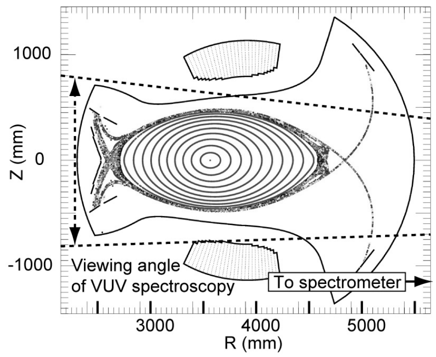

Fig. 1. Observation range of the VUV spectroscopy and edge magnetic fields.

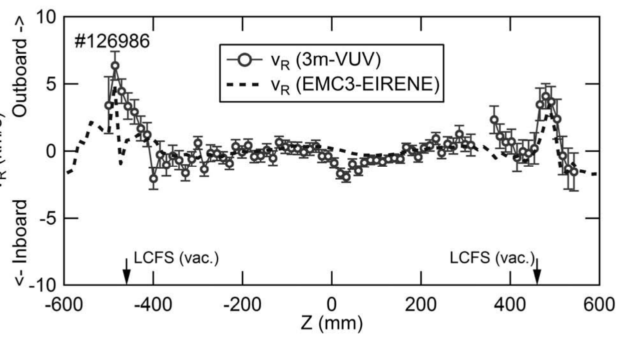

Fig. 2. Vertical profile of C^{3+} impurity flow measured by VUV spectroscopy. A synthetic profile of the C^{3+} flow simulated with EMC3-EIRENE code is also plotted with a dashed line.

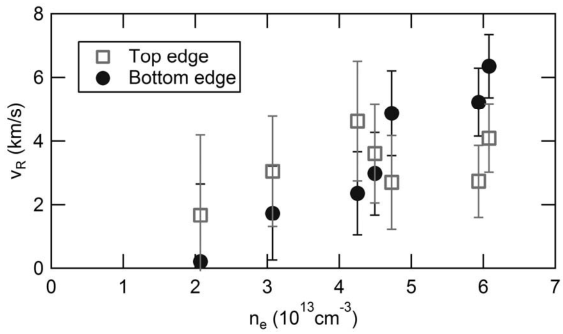

Fig. 3. Observed C^{3+} flow at the top and bottom edges of the ergodic layer as a function of density.

1) Oishi, T. et al.: Applied Optics **53** (2014) 6900.
2) Kobayashi, M. et al.: Nuclear Fusion **53** (2013) 033011.