§8. Density Estimation of Tungsten through Profile Measurement of Zn-like (W^{44+}) WXLV in LHD

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Spectra from tungsten injected with an impurity pellet have been observed in LHD in wavelength ranges of visible to EUV [1]. The EUV spectra with unresolved transition array (UTA), e.g., 6g-4f, 5g-4f, 5f-4d and 5p-4d transitions for $W^{+24-+33}$, measured from LHD plasmas are compared with those measured from Compact electron Beam Ion Trap (CoBIT) with mono-energetic electron beam (≤2keV). The tungsten spectra from LHD are well analyzed based on the knowledge from CoBIT tungsten spectra distinguished into each charge state. On the other hand, the tungsten density in LHD plasmas is analyzed as the first trial from radial profile of Zn-like WXLV (W^{44+}) 4p-4s transition at 60.9Å based on the emission rate coefficient calculated with HULLAC code. As a result, a total tungsten ion density of $3.5x10^{10}cm^{-3}$ at the plasma center is reasonably obtained.

The intensity of Zn-like tungsten is analyzed for the electron temperature recovery phase after impurity pellet injection at t=3.85s, as indicated with hatched area in Fig.1 (b). The measured Zn-like WXLV intensity plotted with solid circles in Fig.1(c) as a function of central electron temperature takes the maximum value at T_e=2.8keV as a sharp function of electron temperature. In the meantime the charge state distribution of tungsten ions in the plasma center of LHD is calculated based on the impurity transport code. The density of Zn-like tungsten (n_W^{44+}) calculated at the plasma center is also plotted in Fig.1(c) with solid line. The electron temperature at which the n_W^{44+} takes the maximum is 4.5keV in the present impurity transport code. A large difference is clearly seen between the observation and the calculation. The reason definitely originates in a discrepancy in the ionization and recombination rate coefficients. The discrepancy of the rate coefficients from ADPAK code is studied for several ionization stages of tungsten. The present result shows a similar tendency to the previous result, that is, the recombination rate of ADPAK is small compared to the experiment.

A typical result of Zn-like WXLV profiles is shown in Fig.2(a). The centrally peaked profile indicates the Zn-like tungsten ion exists in the plasma center. In order to compare with the impurity transport calculation, the chord-integrated vertical profile of Zn-like tungsten in Fig.2(a) is reconstructed to the local emissivity profile using Abel inversion technique. The resultant profile plotted in Fig.2(c) with solid line seems to have two components. It is probably an effect of the line blending with tungsten emission from ions in lower ionization stage. The radial emissivity profile of Zn-like tungsten is also calculated with different electron temperatures, as seen in Fig.2(b). In this calculation the tungsten ion density integrated along the whole plasma volume is assumed to be 10^{-4} to the electron density. In order to determine the tungsten density the measured local emissivity profile in Fig.2(c) is compared with the transport calculation. The best fitting to the measured profile is obtained at T_e=4.6keV, as shown in Fig.2(c) with dotted line. From this analysis the n_W^{44+} is estimated to be $1.4x10^{-4}$ to the electron density of $4x10^{13}cm^{-3}$ at the plasma center. The total tungsten density in the plasma center can be then evaluated from n_W^{44+} to be $3.5x10^{10}cm^{-3}$ ($n_W/n_e=8.8x10^{-4}$). The total radiation loss, P_{rad}, is calculated with average ion model using the present tungsten density. We roughly estimate the value as P_{rad}=4MW. Since the measured P_{rad} in the present discharge ranges in 3-4MW after the tungsten pellet injection, the estimated P_{rad} from the present analysis seems to be reasonable.

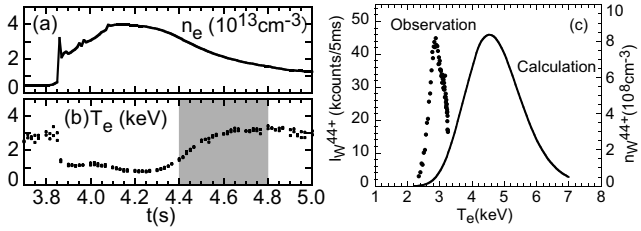

Fig.1 Waveforms of (a) electron density and (b) temperature after injection of cylindrical carbon pellet ($1.2mm^{\phi}\times1.2mm^{L}$) with tungsten in LHD and (c) temperature dependence of Zn-like (W^{44+}) 4p-4s transition at 60.9Å

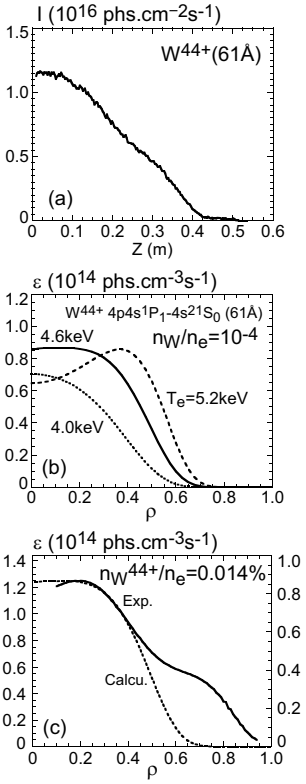

Fig.2 Observed vertical intensity profile and (b) calculated local emissivity profile of Zn-like (W^{44+}: 60.9Å) 4p-4s transition and (c) determination of W^{44+} ion density.

1) Morita, S. et al., AIP Conference Proceedings **1545** (2013) 143.