§38. Validation on Atomic Data and Modeling using Spectroscopy for Multi-charged Ions of Impurities in LHD Plasmas

Murakami, I., Suzuki, C., Morita, S., Goto, M., Oishi, T., Kato, D., Sakaue, H.A., Tamura, N.,
Nakamura, N. (Univ. of Electro-Communications),
Hutton, R., Zou, Y., Yang, Y., Xiao, J. (Fudan Univ.),
Brage, T. (Lund Univ.),
O'Mullane, M. (Univ. Strathclyde)

Spectroscopic diagnostics for impurity ions in plasmas require atomic data and a spectroscopic model in high accuracy to analyze spectra and to extract useful information on plasma parameters and impurity transport study. The spectroscopic model gives relationship between spectral line intensities and electron temperature and density and its accuracy depends on both accuracy of atomic data used in the model and assumption on the model, i.e. number of electron configurations and atomic processes considered in the model. It is necessary to validate the model by comparing calculated spectra with measured spectra to have a better model. We aim to validate the atomic data and model for impurity ions using LHD and electron beam ion trap (EBIT) devices to improve the spectroscopic model in this research.

Tungsten is one of hottest elements studied nowadays for atomic data and modeling by many theoretical and experimental research groups, since tungsten as plasma-facing material in fusion devices will be harmful to keep high temperature core plasma and necessary to be controlled, but the atomic data and model for spectroscopic diagnostics are not fully studied yet in good accuracy and not all data are available for the model.

We have developed a collisional-radiative (CR) model for tungsten ions with atomic data calculated by the HULLAC atomic code[1)] and applied it to calculate spectra of tungsten ions comparing with measured spectra to validate the model as well as to understand tungsten behavior in LHD plasmas. Using compact EBIT (CoBIT) we measured extreme ultraviolet (EUV) spectra of tungsten by controlling electron beam energy and charge states were identified for measured emission peaks. Emission peaks at 2-4 nm wavelength range in the spectra of CoBIT were well agreed with the calculated one. We applied this model to analyze EUV spectra measured in LHD plasma, into which we injected a TESPEL with tungsten inside or a tungsten pellet. We obtained tungsten charge state distribution by fitting the measure EUV spectra with calculated ones[2)].

In the 18th cycle experimental campaign, we tried to measure low charged W ions in LHD plasmas. Pm-like ions have been interested since Curtis and Ellis[3)] proposed strong 5s-5p transition lines for spectroscopic diagnostics but they are not found experimentally yet. Theoretically the ground state of Pm-like ions changes from $4f^{13}5s^2$ to $4f^{14}5s$ for Z higher than ~77. Kobayashi et al.[4)] measured Pm-like Bi (Z=83) with CoBIT and found 5s-5p transition lines are very weak even though its ground state is $4f^{14}5s$. For the case of Pm-like tungsten, W^{13+}, the ground state is $4f^{13}5s^2$ and there are several theoretical and experimental studied[5-7)]. We measured EUV spectra in LHD plasma with low temperature to find W^{13+} ions. At the same time we extended our CR models to lower charged tungsten ions.

Figure 1 shows calculated spectra of W XIII - XV (W^{12+} - W^{14+}) using the CR model. Figure 2 shows EUV spectra measured in LHD plasma. Due to decrease of electron temperature, quasi-continuum structure became higher intensity from t=5.05s to 5.35s at wavelength 160-250 Å. Probably spectral structure of W XIV in this wavelength region is embedded in this quasi-continuum structure, so it is difficult to indentified structure of each ion.We need further investigation on both measured EUV spectra and calculated ones in more detail for future study.

1) Bar-Shalon, A. et al., J. Quant. Spect. Rad. Transf. **71**, 179 (2001).
2) Murakami, I. et al., Nucl. Fusion, **55**, 093016 (2015).
3) Curtis, L. J and Ellis, D. G., Phys. Rev. Lett. **45**, 2099 (1980).
4) Kobayashi, Y. et al., Phys. Rev. A **89**, 010501(R) (2014).
5) Safronova, U. I. et al., Phys. Rev. A **88**, 032512 (2013).
6) Kobayashi, Y. et al., Phys. Rev. A **92**, 022510 (2015).
7) Zhao, Z. Z. et al., J. Phys. B **48**, 115004 (2015).

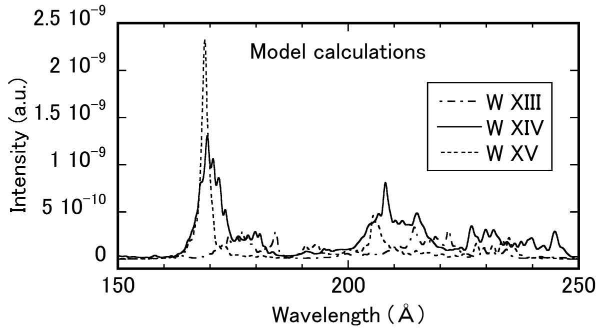

Fig. 1 Calculated spectra of W XIII – XV using the CR model with electron temperature 300eV and electron density $10^{13}cm^{-3}$ assumed.

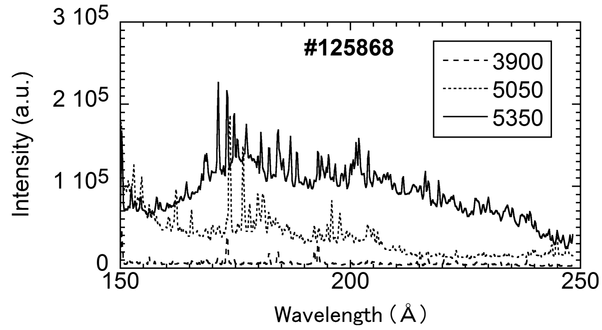

Fig. 2 EUV spectra taken by an EUV spectrometer in LHD. Central electron temperature was higher than 1keV at t=5.05s (dotted line), and decreased lower at t=5.35s (solid line).