# §10. Spectroscopic Studies on Transport of Heavy Impurities

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Tungsten is one of the candidates for plasma facing components in future fusion devices such as ITER and DEMO. However, because of its high Z number, tungsten is not fully ionized in plasma, and the intense line-radiation dissipates plasma energy, leading to plasma collapses. Hence it is of significance to avoid accumulation of tungsten ions in core plasma. For this purpose, it is required to establish a method to determine tungsten ion density in the plasma quantitatively. Spectroscopic measurement of tungsten spectra has been widely used and analysis with an atomic code has been extensively performed. In the present work, two tungsten spectra measured in LHD was analyzed with an atomic code, named FAC [1]: one was taken from a low temperature plasma ( $T_e(0)$ = 0.5 keV ) in 2010 campaign, and the other from a high temperature plasma ( $T_e(0)$ = 3 keV ) in 2011 campaign, respectively, shown in Fig. 1 (a) and (b).

Spectrum calculation with FAC was performed for $W^{14+}$ - $W^{71+}$. In the calculation, for instance, for $W^{27+}$ ( Ag-like tungsten ion ), the following electron configurations besides the ground state ( $4d^{10}$ 4f ) were considered:

$4d^9 + 4f^2$

$4d^{10}$ + 5s, 5p, 5d, 5f, 5g, 6s

$4d^9$ 4f + 5s, 5p

In calculation for $W^{14+}$ - $W^{24+}$, only $\Delta n$=0 transitions between $n$=4 level were considered because it was found that calculation of $\Delta n$=1 transitions from $n$=5 to $n$=4 consumed huge computation time. Then, a collisional-radiative model, which included the processes of (de-) excitation between these levels and radiative transition from these levels, was used to calculate spectra of Each W ion. As shown in Fig. 2, many spectral lines due to transitions between 4p - 4d and 4d - 4f were distributed between 4.5 nm and 5.5 nm. These spectra were summed up and a synthesized spectrum was obtained. In Fig. 1 (a), comparison of the measured and the synthesized spectrum at 0.5 keV is shown. Except for several peaks around 5.0 nm, no good agreement between the measured and the synthesized spectrum is obtained. In particular, at the broad peak at a wavelength of 5.7 nm, disagreement of intensity is significant. Although the spectra due to 4d-4f transitions of $W^{14+}$ - $W^{24+}$ contribute to the broad peak, they are not sufficient. Since preliminary calculation indicates $\Delta n$=1 transitions from $n$=5 to $n$=4 give quasi-continuum spectrum around 5.7 nm, it is possible that agreement is obtained by including the $\Delta n$=1 transitions. However, as described above, huge computation time is required for this calculation. Hence careful consideration about which transitions to be considered is a key for calculation.

In contrast, good agreement for the spectrum taken at 3 keV is obtained as shown in Fig. 1 (b). In particular, several sharp peaks from highly charged W ions ( $W^{39+}$ - $W^{45+}$ ) were found for the first time in LHD. Among these peaks, the peaks indicated by $W^{44+}$ and $W^{45+}$ at 6.1 nm and 6.2 nm are isolated from spectral lines from other W ions. Hence these lines are useful to determine the $W^{44+}$ ion and the $W^{45+}$ ion density [2]. Note that in order to determine a W ion density from the spectrum, absolute sensitivity calibration for the spectrometer is required. This will be a future work.

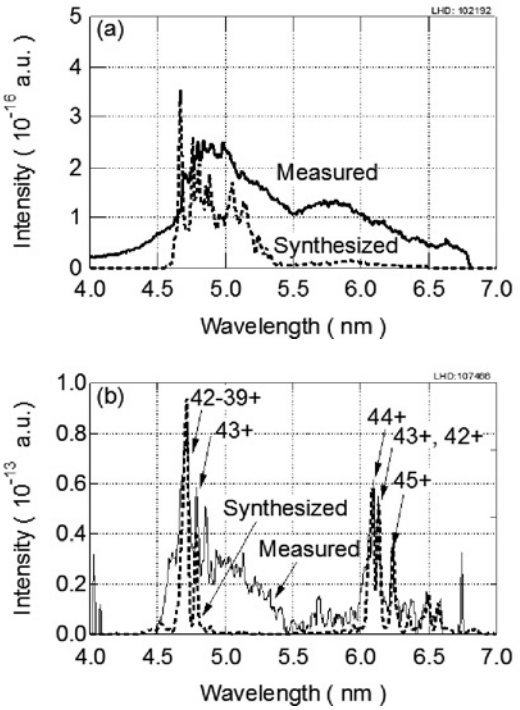

Fig. 1. Measured and synthesized spectrum at an electron temperature of (a) 0.5 keV and (b) 3 keV.

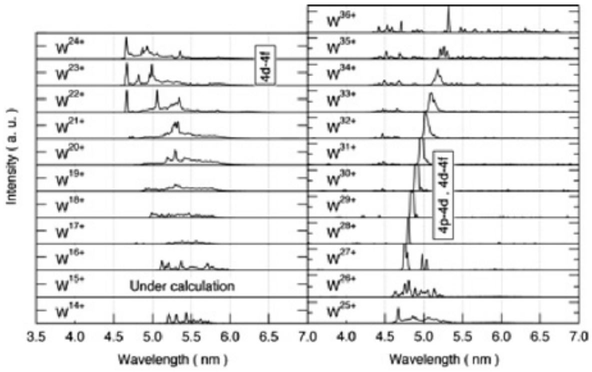

Fig. 2. Calculated spectrum with FAC code.

1) Gu, M. F. et al., Astrophys. J. 582 (2003) 1241.
2) Nakano, T. et al,: J. Nucl. Mater. **415** (2011) S327-S333.