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§9. Collisional-radiative Models of W Ions for Plasma Diagnostics

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Tungsten is planned to be used as plasma facing material for a divertor plate or the first wall of ITER and fusion reactors because of low erosion yield and low deuterium retention. However, once tungsten is sputtered into plasma, it is transferred to a core plasma region and causes serious radiation loss to cool the plasma. In order to estimate amount of radiation loss and concentration of tungsten in plasmas, spectroscopic measurement is necessary and a spectral model is required to analyze spectra to obtain tungsten ion densities. A collisional-radiative (CR) model is widely used to estimate spectral line intensities with given electron density and temperature. The CR model solves rate equations of excited states with steady-state assumption, and the model includes electron collision processes between excited states.

We have been constructing two kinds of CR models for W ions. One is to calculate ion abundances and the other is to calculate spectral lines. We use the HULLAC code[1] to calculate atomic data for the CR models.

The first CR model can calculate W ion abundance in ionization equilibrium for electron temperature Te = 0.1 – 5keV with W^{11+} ~ W^{53+} ions. In this model, only configurations of excited states are considered and fine structures are ignored. Figure 1 shows calculated ion abundance for electron density $10^{14}cm^{-3}$. At a given electron temperature, 10 abundant ions are selected in the calculation and total abundance is taken to be 1[2].

The second CR model can calculate spectra of W ions at given electron temperature and density. Fine structures of excited states are considered. In this model, recombination processes are not included. So far we have CR models for tungsten ions from W^{20+} up to W^{55+} ions, with excited levels up to 20000 levels for one ion. We applied this model to examine spectra measured by the compact electron beam ion trap device (CoBIT)[3] to validate the CR model.

Combining results of both CR model, we can synthesize spectra for plasma in ionization equilibrium. Figure 2 shows synthesized spectra for plasma in ionization equilibrium with Te=1keV and 530eV. We can reproduce the double peak feature of unresolved transition array (UTA) at 4.5-7nm which is commonly observed in fusion plasma with Te ~ 1keV in LHD and ASDEX Upgrade[4]. This UTA is produced by 4f-4d and 4d-4p transitions of W^{28+} ~ W^{35+}. The peak is shifted to shorter wavelength for Te=530eV case from the case of Te=1keV. The many peaks at 2-3nm are lines of 5g-4f and 5f-4d transitions for W^{20+} - W^{30+} ions. These peaks are identified by the CoBIT measurements and the CR model[3].

These synthesized spectra have the same characteristic features of measured spectra, but sill some discrepancies are remained. We need to improve the synthesize model further by considering the line-of-sight effect which pass through the plasma with electron temperature and density distributions.

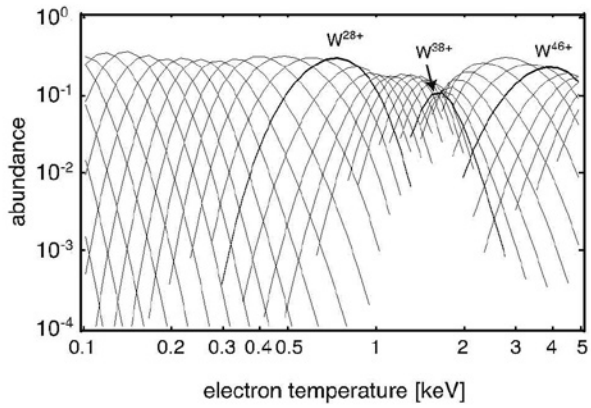

Fig. 1 Ion abundance distribution of W ions in ionization equilibrium calculated by the first CR model in which only configurations are considered[2].

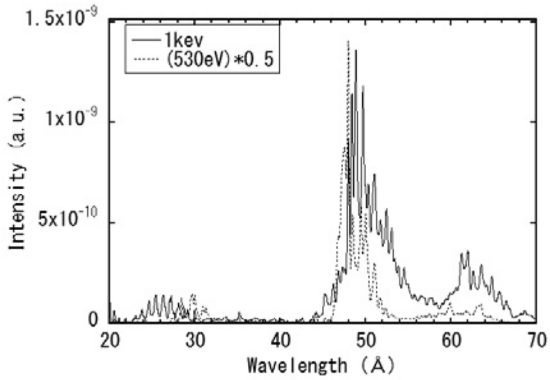

Fig. 2. Synthesized extreme ultraviolet spectra calculated with the second CR model in which fine structure levels are considered for each ion. Electron temperature of 1keV (solid line) and 530eV (dashed line) are assumed. Ion abundances are calculated with the first CR model.

1) Bar-Shalon, A. et al., J. Quant. Spect. Rad. Transf. 71, 179 (2001).
2)Sasaki, A and Murakami, I., submitted to J. Phys. B (2013).
3) Sakaue, H. A. et al., AIP Conf. Proc. Vol. 1438, (AIP), in press (2012).
4) Pütterich, T. et al., Plasma Phys. Control. Fusion 50, 085016 (2008).