§8. Study on Non-equilibrium Ionization of Highly Charged Tungsten Ions by Using Forbidden Lines

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A novel idea of this work is to use UV-visible forbidden lines to measure W^{q+} ions distributions in the Large Helical Device (LHD). Inherently narrow natural width of the forbidden lines is a suitable feature for identifying a specific charge state of ions in emission spectra. In the last LHD cycle, an M1 line of W^{27+} has been clearly identified, and its intensity distribution on a poloidal cross section was measured. The measured intensity distribution was compared with calculated W^{27+} ion distribution.

Discharges for present measurements were started with electron cyclotron heating followed by hydrogen neutral beam injection (NBI) heating. In steady state, the maximum electron temperature is about 3 keV at the plasma center. Then, a solid pellet containing tungsten was injected into background hydrogen plasmas. Time-resolved (sampling time of 38 ms at every 100 ms) measurements were performed using Czerny-Turner UV-visible spectrometers equipped with CCD detectors. Using an optical fiber array, photon emission was observed at 40 lines of sight divided along the vertical direction (Z) of a horizontally elongated poloidal cross section.

Fig. 1 shows a UV line emission measured after a tungsten pellet injection. The line at 337.82 nm is identified as the magnetic-dipole (M1) transition, 4f $^2F_{5/2}$ - $^2F_{7/2}$, of W^{27+} ions. This M1 line has been discovered by using an electron beam ion trap at Fudan University [1]; its wavelength was determined to be 337.84 nm. Vertical profile of the M1 line emission indicates a line intensity distribution localized inside the core plasma where electron temperatures are high enough to produce the W^{27+} ions. In the spectrum, another three lines are also identifies as emission lines of W^{q+} ions, because its vertical profiles are similar to that of the M1 line at 337.82 nm.

Fig. 2 shows an intensity distribution of the M1 line along the effective small radius, which is transformed from the vertical profile. In the ionization equilibrium assumption, W^{27+} ion distributions are calculated using a measured T_e profile and available data for ionization/recombination rate coefficients. ADPAK data gives the ion distribution consistent with the M1 line intensity distribution.

1) Fei, Z. et al. Phys. Rev. A 86 (2012) 062501.

2) Asmussen, K. et al., Nucl. Fusion 38 (1998) 967-986.

3) Sasaki A. and Murakami, I., J. Phys. B 46 (2013) 175701.

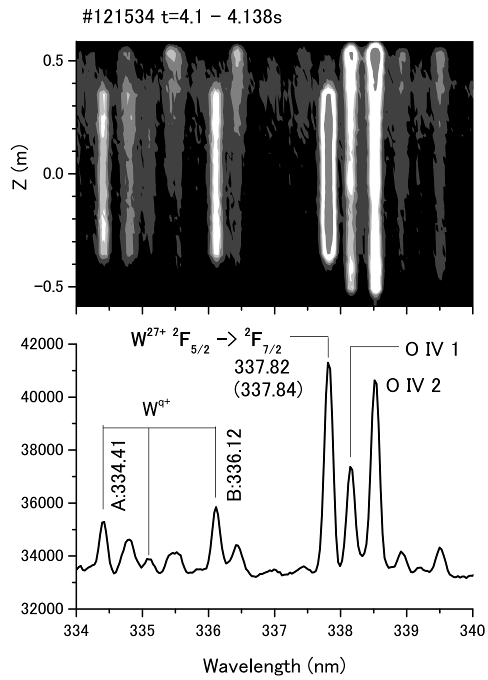

Fig. 1: A UV line emission measured after a W pellet injection (t=4.0 s) at the LHD. Upper: A CCD image for Z-distribution of line intensities integrated along lines of sight (see text). Lower: the UV line spectrum.

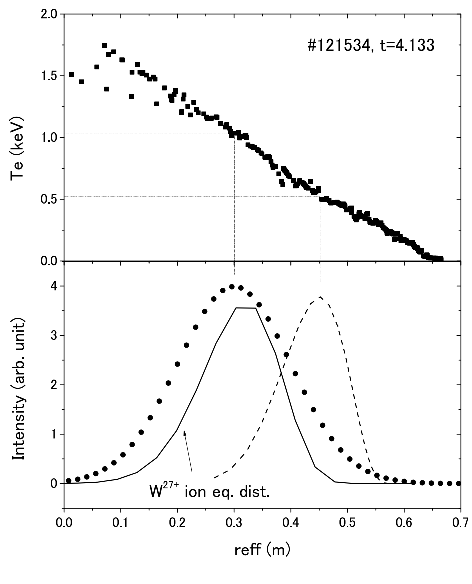

Fig. 2: An intensity distribution of the M1 line at 337.82 nm along the effective small radius. Upper: T_e distribution. Lower: Radial distributions of the M1 line intensity (dot) and W^{27+} ions calculated assuming the ionization equilibrium with ionization/recombination rate coefficients, ADPAK (solid) [2] and Sasaki [3] (dashed).