§22. 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 near UV-visible forbidden lines to measure W^{q+} ions distributions in the Large Helical Device (LHD). In this series of study, we have identified magnetic-dipole (M1) lines from $W^{q+}(q = 26-28)$ ions in $320-356$ nm and $382-402$ nm. In the present work, spatial distributions of an M1 line (337.7 nm) intensity of W^{27+} is analyzed by using a collisional-radiative model, and W^{27+} density distributions in core plasmas are deduced.

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 polyethylene pellet containing tungsten wire (0.6 mm long and 0.15 mm diameter) 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 44 lines of sight on a horizontally elongated poloidal cross section.

A collisional-radiative (CR) model is developed to analyzet the M1 line lintensity. HULLAC code is used to generate atomic data (energy levels, radiative transition rates, electron collision strengths). Proton collision effects are included in the model approximating proton collision strengths as mass scaled electron collision strengths. Ionization excitation from the next lower charge state is also taken into account. Rate coefficients are calculated assuming the Maxwellian velocity distribution of electrons and protons. It is assumed that electrons and protons have an identical temperature and a density. Fractional ion abundances of W^{q+} are calculated using ionization and recombination rate coefficients. There is a large uncertainty in the rate coefficients, nevertheless calculated W^{27+} fractional abundance has a maximum around $T_e = 1$ keV. The local intensity of the M1 line at each effective minor radius on the poloidal cross section is calculated using T_e and n_e profiles measured by Thomson scattering. Vertical distributions of the M1 line intensity are obtained by integrating the local intensities along each line of sight.

Vertical distributions for the M1 line intensity of W^{27+} are shown in Fig. 1. The present model gives the vertical profile of good agreements with the measured profile. The proton collision effect increases fractional population of the ground state, which results in an enhancement of the M1 line intensity by about 40 %. Radial distribution of W^{27+} is deduced based on the measured vertical profile (Fig. 2). The initial ion density distribution has a maximum at the effective minor radius (r_{eff}) of 0.3 m where the fractional W^{27+} abundance becomes the maximum at the local electron temperature, *i. e.* $T_e = 1$ keV. The peak position of the radial distribution moves toward the plasma center ($r_{\mathrm{eff}} = 0$) as the temperature at the plasma center decreases with time. The W^{27+} density in the core plasma is initially increased after the pellet injection (4.1 - 4.3 s) accompanying a temperature drop and a density rise. Since the temperature and density are stable in later times (5.0 - 5.6 s), the apparent decrease in the ion density at the core plasma indicates diffusion of the tungsten ions after confinement in the plasma center.

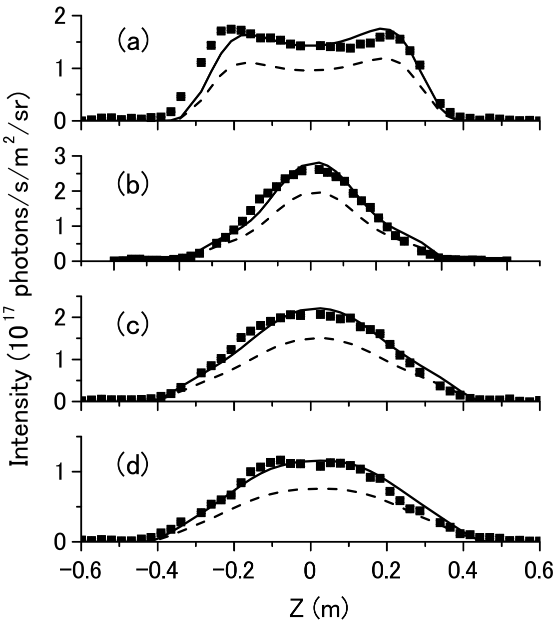

Fig. 1: Vertical distributions of W^{27+} M1 line intensities at (a) $t = 4.1$, (b) 4.3, (c) 5.0 and (d) 5.6 s. Tungsten pellet is injected at 4.0 s. Solid squares indicate measurement and solid curves calculations, respectively. Dashed lines are the calculation neglecting proton collision effect.

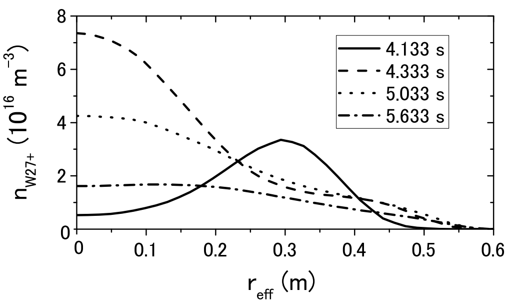

Fig. 2: Radial profile of W^{27+} ion distributions deduced from vertical profiles of the M1 line intensity in Fig. 1. Peak temperatures at the plasma center are 2.0, 1.0, 1.0, and 1.2 keV at 4.1, 4.3, 5.0 and 5.6 s, respectively.