# §4. Spectroscopic Diagnostics of Line Emissions from Tungsten Ions in Various Ionization Stages in LHD

Oishi, T., Morita, S., Huang, X.L., Zhang, H.M., Liu, Y., Goto, M.

Behavior of multiply charged ions in fusion plasmas represented by tungsten ions has attracted attention because tungsten is regarded as a leading candidate material for the plasma facing components in ITER and future fusion reactors. Considering tungsten impurity transport in ITER, the following three transport processes need to be evaluated: (1) release of neutral tungsten atoms from the divertor plates; (2) transport of tungsten ions at lower ionization stages in the edge plasmas; and (3) accumulation of tungsten ions at higher ionization stages in the core plasmas. Therefore, we conducted spectroscopy diagnostics to measure spectra of emissions released from tungsten ions in Large Helical Device (LHD).

Figure 1 shows wavelength spectra of line emissions from tungsten ions in various ionization stages measured in a hydrogen discharge in LHD. Tungsten ions were introduced in the LHD plasmas by injecting a graphite or polyethylene pellet containing a small piece of tungsten metal[1]. Central electron density and temperature just before the pellet injection was $2 \times 10^{13}$ cm$^{-3}$ and 3 keV, respectively. Three neutral hydrogen beams based on negative ion sources with total port-through power of 8 MW were injected. Figure 1(a) shows a spectrum measured using a 3 m normal incidence vacuum ultraviolet (VUV) spectrometer covering the wavelength range of 300-3200 Å[2]. Recently, it was found that some WVI lines, such as WVI 677.7 Å, are emitted with extremely high intensity and entirely isolated from other intrinsic impurity lines[3]. Figures 1(b) and (c) show spectra measured using two flat-field extreme ultraviolet (EUV) spectrometers covering the wavelength range of 10-130 Å and 50-500 Å, respectively. The line emissions of WXXV 32.3 Å, WXXVI 30.9 Å, WXXVII 29.6 Å, WXLII 131.2 Å, WXLIII 129.4 Å, WXLIV 126.3 Å, and WXLVI 127.0 Å have been observed.

The temporal evolution of the line emission was investigated, as shown in Fig. 2. The electron temperature drops and the electron density increases rapidly when the pellet is injected as shown in Fig. 2(a). Figures 2(b), (c), and (d) show the temporal evolutions of line emission intensities evaluated by the area of the spectral peaks for the WVI, WXXV, WXXVI, WXXVII, WXLII, WXLIII, WXLIV, and WXLVI lines. The line intensity of WVI (ionization potential $E_i$ = 64.8 eV) increased once at the timing of the pellet injection and turned to decrease down to 4.3s as shown in Fig. 2(b). The WXXV, WXXVI, and WXXVII ($E_i$ = 734.1 eV, 784.4 eV, and 833.4 eV, respectively) lines increased subsequently because the electron temperature recovered by a continuous neutral beam heating. Finally, the WXLII, WXLIII, WXLIV, and WXLVI ($E_i$ = 1994.8 eV, 2149.2 eV, 2210.0 eV, and 2414.1 eV, respectively) lines increased in the latter half of the discharge. Their sequential increasing behavior is reasonable when considering the relationship between the electron temperature and their ionization energies.

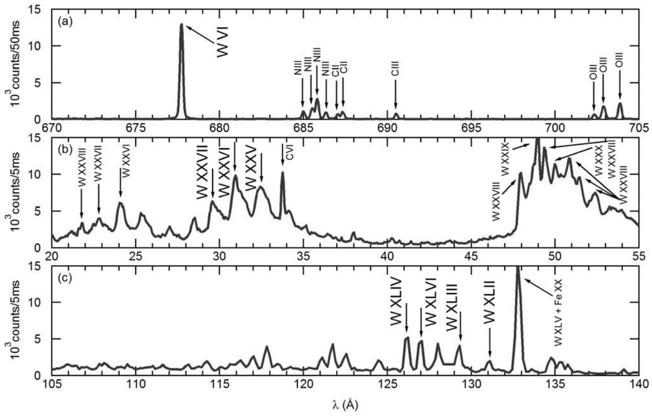


Fig. 1. Tungsten spectra measured by (a) a 3m VUV normal incidence spectrometer and (b,c) two flat-field EUV spectrometers in LHD.

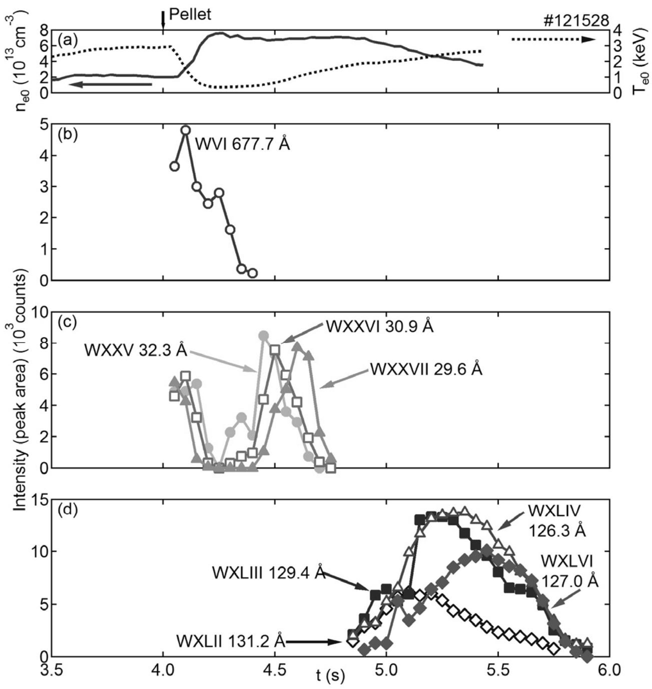


Fig. 2. (a) Temporal evolutions of central electron density $n_{e0}$ and temperature $T_{e0}$ in a hydrogen discharge with tungsten pellet injection. Line intensities of (b) WVI 677.7 Å, (c) WXXV 32.3 Å, WXXVI 30.9 Å, and WXXVII 29.6 Å, and (d) WXLII 131.2 Å, WXLIII 129.4 Å, WXLIV 126.3 Å, and WXLVI 127.0 Å are shown together.

1) Huang, X.L. et al.: Rev. Sci. Instrum. **85** (2014) 11E818.
2) Oishi, T. et al.: Applied Optics **53** (2014) 6900.
3) Oishi, T. et al.: Physica Scripta **91** (2016) 025602.