§12. Observation of EUV Spectra from Highly Charged Bismuth Ions in LHD

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Extreme ultraviolet (EUV) spectroscopy of highly charged high Z ions in plasmas has recently become one of great interests in terms of some applications as well as basic atomic physics. For example, the development of a compact and bright EUV light source in water window wavelength region (2.3–4.4 nm) has strongly been desired for three-dimensional imaging of microscopic biological structures *in vivo*. Though laser-produced bismuth plasma has been studied as a candidate for the light source[1)], benchmarking of the measured spectra with theoretical calculations is difficult because of the effects of line broadening and self-absorption in optically thick plasmas. On the other hand, low density plasmas produced in LHD are more suitable for the benchmarking because of the optically thin condition and the availability of high resolution Thomson scattering diagnostic.

In the last experimental campaign, therefore, we have preliminary tried to measure EUV spectra from bismuth ions by pellet injection into LHD plasmas. Following an injection of a tracer-encapsulated solid pellet into a hydrogen plasma, the EUV spectra in 2.5–5 nm region were recorded by a 2 m Schwob Fraenkel grazing incidence spectrometer[2)]. The grating with 600 mm^{-1} groove density was used for better wavelength resolution. The frame rate of the detector was fixed at 0.1 s.

An example of the time evolution of a discharge with a bismuth pellet injection is shown in Fig. 1, where neutral beam injection (NBI) heating power (P_{NBI}), stored energy (W_p), central electron temperature ($T_e(0)$), line averaged electron density ($\langle n_e \rangle$) and total radiated power (P_{rad}) are drawn. The total radiated power rapidly increased at the time of the pellet injection at 3.8 s. When the neutral beams are switched from tangental ones to vertical ones at 5.3 s, the central electron temperature rapidly dropped to zero because of the formation of an unusual hollow plasma. The electron temperature along the line of sight after 5.5 s was always kept below 0.5 keV.

Figure 2 shows EUV spectra before (at 3.75 s) and after (at 5.25 s) the pellet injection in this shot. Apart from the intrinsic C^{5+} spectral line at 3.37 nm, only a broad quasicontiniuum feature with a peak around 4 nm was observed after the pellet injection until 5.5 s. After 5.5 s, no strong emission from bismuth ions was observed. According to the theoretical calculation[1)], the quasicontiniuum feature around 4 nm arises from n=4–4 transition arrays of a wide range of charge states. Though the calculation also suggests that another quasicontiniuum feature would appear around 3 nm when the electron temperature is above 1 keV, it was not observed in this experiment. Further experiments with wider ranges of discharge parameters will be planned in the next experimental campaign.

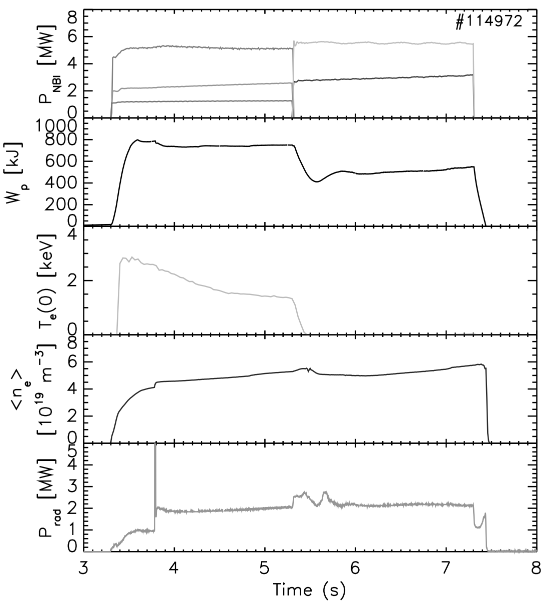

Fig. 1: Time sequences of NBI heating power (P_{NBI}), stored energy (W_p), central electron temperature ($T_e(0)$), line averaged electron density ($\langle n_e \rangle$) and total radiated power (P_{rad}) in a LHD discharge with a bismuth pellet injection at 3.8 s.

1) Higashiguchi, T. et al.: Appl. Phys. Lett. **100** (2012) 014103.

2) Schwob, J. L., Wouters, A. W. and Suckewer, S.: Rev. Sci. Instrum. **58** (1987) 1601.

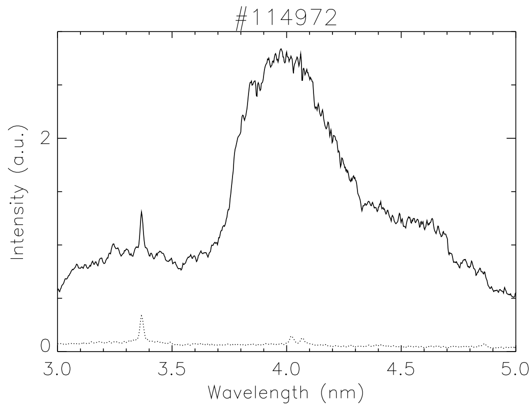

Fig. 2: The EUV spectra observed in the discharge shown in Fig. 1 for different timings before (broken line) and after (solid line) the tungsten pellet injection. The spectra at 3.75 s and 5.25 s are drawn by broken and solid lines, respectively.