§73. High-resolution Visible Spectroscopy of Forbidden Lines of High-Z Impurity Ions

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Ground-term fine-structure splitting of highly charged heavy ions falls into visible wavelength ranges. Precise measurements of forbidden lines of transitions in the fine-structure give a benchmark for accurate relativistic theories of atomic systems. Recently, Katai et al. [1)] reported a precise measurement of the magnetic-dipole line at 4139 Å of Ti-like Xe^{32+} ions ($3d^4\ {}^5D_{2\text{-}3}$ ground-term fine-structure) at Large Helical Device (LHD). The experimental uncertainty was reduced even smaller than uncertainties of previous measurements by means of electron-beam-ion-traps [2)]. This demonstrates that LHD can sustain high-temperature plasmas with significant amount of heavy ions, and serve as an apparatus for precise measurements of weak forbidden lines of highly charged ions.

Uncertainties inherent in theoretical predictions of many-electron systems are largely due to inaccuracy in calculations of electron correlations. For highly charged heavy ions, relativistic effects, e.g. Breit interaction, also become very important in the electron correlation. The benchmark measurement, therefore, serves to improve our knowledge on the relativistic electron correlation observed in atomic structures of highly charged ions.

Besides atomic physics interests, visible forbidden lines have useful characters for plasma diagnostics. Its narrower line widths are preferable to measure Doppler-widths which represent ion temperatures. Doron et al. [3)] examined theoretically electron density dependence of magnetic-dipole lines of N-shell tungsten ions in visible and UV ranges, and suggested that intensity ratios of some line pairs would be useful for the density diagnostics of fusion plasmas. Also, it is intriguing to investigate applicability of the forbidden lines for studies on heavy impurity ion transport. The forbidden lines may be emitted in areas distant from where the ions are excited by electron collisions, because of its longer life-time (~ ms). This contrasts to strong allowed line emissions which take place immediately after the collisional excitation. The present study is, therefore, motivated in viewpoints both of the atomic physics and the plasma diagnostics.

In the 14th cycle of LHD experiments, newly developed impurity pellet was tested with tungsten successfully, and visible spectra of the tungsten were measured in wavelength range of 345 – 410 nm. In order to sustain LHD plasmas with heavy impurity ions, amount of the heavy impurity injection must be controlled. To reduce the injected amount of heavy impurities, the impurity container was made of carbon pellets. By changing the amount of the heavy impurity in the carbon pellet, the amount of the impurity injection can be controlled. Due to limited dynamic ranges of spectrometers, separate measurements were performed in three adjacent wavelength regions in 345 – 410 nm. Fig. 1 shows measured spectra for ablation clouds of the impurity pellet. By comparing two spectra measured with tungsten and without tungsten, many lines of W I and W II can be identified clearly.

Searches for the forbidden lines in other spectra measured in this cycle are still ongoing. In order to catch faint forbidden line emissions, we may need to learn in the next cycle how to prevent plasmas from radiation collapse even with larger amounts of the tungsten injection.

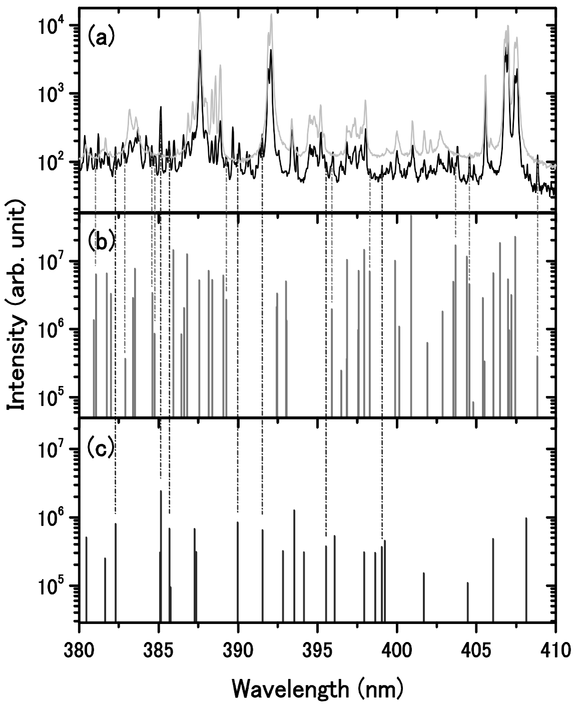

Fig. 1. Visible spectra observed in ablation clouds of the impurity pellets with tungsten (black) and without tungsten (light gray). b,c) LTE spectra of W I and W II, respectively, synthesized with atomic data in NIST-ASD database. Electron temperature of 3 eV is assumed.

1) Katai, R. et al., PFR:Letters **2** (2007) 006.
2) Watanabe, H. et al., Phys. Rev. A **63** (2001) 042513.
3) Doron, R., Feldman, U., Phys. Scr. **64** (2001) 319.