§87. Observation and Analysis of EUV Spectra from Open 4f Subshell High Z Ions in LHD

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Extreme ultraviolet (EUV) emission spectra from high Z ions in plasmas have recently drawn considerable attention in terms of some applications as well as basic atomic physics. For future development of semiconductor lithography, for example, gadolinium or terbium ions are being considered as potential light sources around 6.7 nm[1, 2]. In fusion research, comprehensive experimental database of spectral emissions from tungsten ions is required because tungsten will be used as a plasma facing component in the forthcoming International Thermonuclear Experimental Reactor (ITER). Several experimental works on quasicontinuum emission from high Z ions with open 4d and 4p subshells have been carried out in fusion experiments[3, 4, 5]. However, information on lower ion stages with 4f, 5s and 5p electrons in their outermost subshells is still insufficient.

In this study we have observed EUV spectra from tungsten, gadolinium and neodymium ions in LHD plasmas. We have chosen the wavelength ranges where the emissions from open 4f or lower charged ions are expected. Following an injection of a tracer-encapsulated solid pellet into a hydrogen plasma, the spectra were recorded by a 2 m Schwob Fraenkel grazing incidence spectrometer[6]. The grating with 600 mm^{-1} groove density was used for better wavelength resolution. Figure 1 shows an example of the spectrum around 18 nm in a plasma with an injection of a tungsten pellet under the low electron temperature below 1 keV. The dominant ion stages in this time period are expected to be W^{23+} and W^{24+}, and the center wavelength of the quasicontinuum feature tends to move towards longer wavelength as the temperature decreases. This tendency agrees with our atomic structure calculations of $n = 5$–5 transitions for tungsten ions with open 4f subshells.

Figure 2 shows an example of the gadolinium spectrum in the 6–9 nm region under the low temperature condition below 240 eV, where an unusual hollow plasma was formed after the pellet injection. In this case, clear spectral narrowing of the quasicontiniuum feature took place and the emission was concentrated in the narrow 0.1 nm bandwidth around 6.8 nm. The dominant ion stage seems to be Ag-like Gd^{17+} because the characteristic double peak at 7.140 and 7.181 nm are identified as 4d–4f transitions of Gd^{17+}. The 4f–5g lines of Gd^{17+} are also found at 6.095 and 6.119 nm. Indeed, Ag-like ions has a single 4f electron outside a closed 4d subshell and their spectral lines tend to clearly appear under relatively low temperature conditions. Atomic structure calculations for a wide range of charge states will be necessary for further analysis to give an insight into the the measured EUV spectra.

1) Kilbane, D. and O'Sullivan, G: J. Appl. Phys. **108** (2010) 104905.

2) Otsuka, T. et al.: Appl. Phys. Lett. **97** (2010) 111503.

3) Fournier, K. B. et al.: Phys. Rev. A **50** (1994) 2248.

4) Pütterich, T. et al.: Plasma Phys. Control. Fusion **50** (2008) 085016.

5) Harte, C. S. et al.: J. Phys. B: At. Mol. Opt. Phys. **43** (2010) 205004.

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

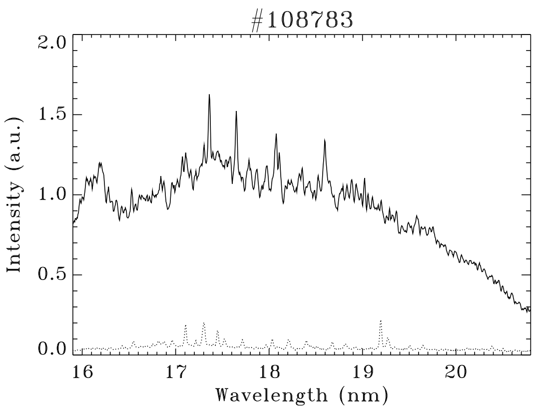

Fig. 1: Spectrum in the 18 nm region measured in LHD with a tungsten pellet injection.

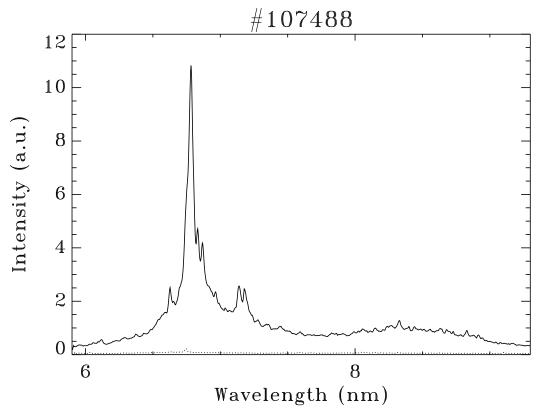

Fig. 2: Spectrum in the 6–9 nm region measured in LHD with a gadolinium pellet injection.