§88. Spectroscopic Measurements and Database Development for Highly Charged Rare Earth Elements

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The spectra of photoemissions due to the transitions between the sub-shell levels in N-sub-shell open atomic ions are of interest for the strong influence from the interactions between the electronic state configurations with different constituent orbitals. Spectral shift and narrowing of the unresolved transition array (UTA) was pointed out [1] and this narrowing effect gives an advantageous situation to the development of the practical extreme ultraviolet (EUV) light sources. To develop the shorter wavelength light source, we are suggested to investigate the heavier elements. The wavelengths of the $4d$ - $4f$ transitions are reported to be, for example, 7.9 nm for Nd (Z=60), 7.0 nm for Eu (Z=63) , and 6.8 nm for Gd (Z=64) [2]. Recently, the 4d-4f transitions of Tb at 6.5 nm has been investigated theoretically by Sasaki et al [3]. The photoemissions from tungsten (W) atomic highly charged ions have recently also drawn a strong attention because W has been considered as one of the wall materials in magnetic confinement fusion (MCF) devices. In the intermediate stage of ionizations W ions also have open N-sub-shells and provide us with the complication of the emission spectra due to the configuration interactions.

In the present work, we inject the rare earth metal elements in LHD plasmas by means of laser brow off to the outer area of the plasmas and by means of the pellets injection to the core area of the plasmas. In the fiscal years of 2010 to 2011, we measured the emission spectra of Gd and Nd in detail. We have obtained the UTA spectra at 6.8 nm for Gd and at 8.0 nm for Nd. The details of the experimental results have been reported in J. Phys. B [4]. We compared the experimental results with elaborate calculations based on the MCDF method with Breit and QED corrections[5-7]. And, also, the spectra from W atomic ions have been measured at somewhat shorter wavelength range. A Gd, Nd, or W pellet has been injected into the plasma with the central electron temperature 2 ~ 3 keV, and the emission lines have been observed. Because the plasma temperature is somewhat higher than that of laser produced plasmas (LPP) for the development of EUV light sources, the EUV spectra from LHD give a good reference as a counterpart at high temperature end.

By analyzing the time evolution of the spectra, we have obtained the EUV spectra from different plasma temperatures. In Fig.1 we show the spectra for Gd ions in LHD plasmas. The upper entry gives the one at the electron temperature Te = 2.0 keV, the middle entry at Te = 0.24 keV, and the lower entry at Te = 1.0 keV, respectively.

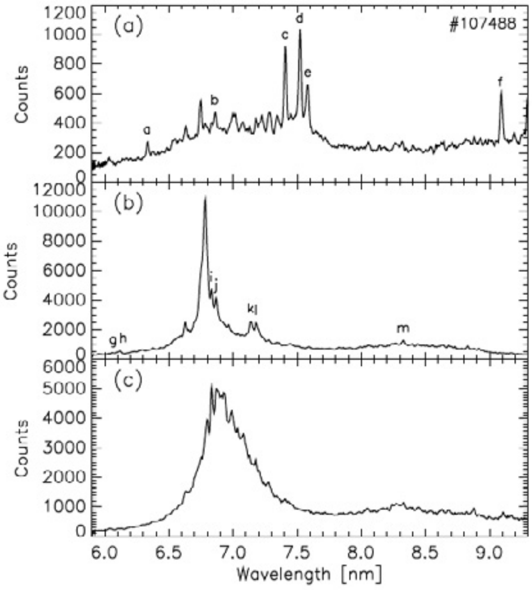

Fig. 1. EUV emission spectra of Gd in LHD plasmas.

In Fig.2 we show the spectra for Nd ions in LHD plasmas. The upper entry gives the one at the electron temperature Te = 1.9 keV, the middle entry at Te = 0.35 keV, and the lower entry at Te = 1.2 keV, respectively.

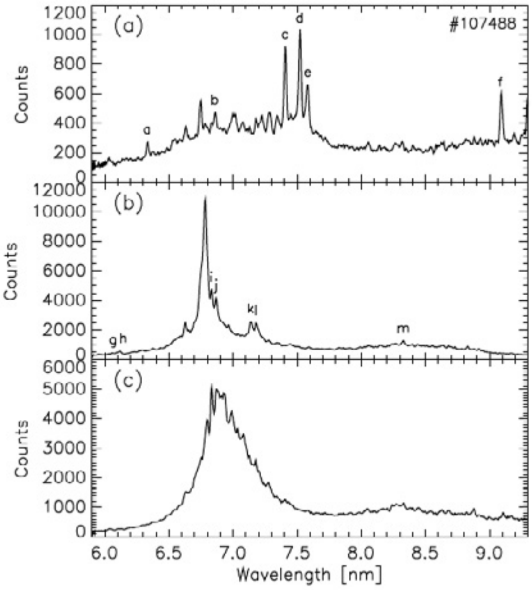

Fig. 2. EUV emission spectra of Nd in LHD plasmas.

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