§7. Systematic Observation of EUV Spectra from Highly Charged Ions of Lanthanide Elements Using LHD Plasmas

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Extreme ultraviolet (EUV) emission spectra from highly charged ions of lanthanide elements (Z=57–71) attract interest in the field of basic atomic physics because of relativistic effects and multi-electron correlation. In addition, they are important also in terms of industrial applications to the next generation light sources for EUV lithography. However, the developments of spectroscopic data and models for these elements are still insufficient. Therefore, studies on Z dependence of the EUV spectra would be scientifically meaningful.

In this study, we have observed EUV spectra from highly charged ions of lanthanide elements with Z=60–70 in LHD plasmas. Small amount of these elements are introduced into LHD plasmas using the tracer-encapsulated solid pellet (TESPEL)[1]. Temporal evolutions of EUV spectra around the 5–10 nm range are recorded by a 2 m Schwob-Fraenkel grazing incidence spectrometer[2] with a frame rate of 5–10 Hz. The grating with 600 mm^{-1} groove density was used for better wavelength resolution. The absolute wavelength has been calibrated with an uncertainty about 0.005 nm by the positions of well-known lines from intrinsic and intentionally injected impurity ions.

The feature of the observed EUV spectra dramatically changes from discrete to quasicontinuum feature as the electron temperature decreases. For example, the discrete spectra measured under relatively higher temperature conditions are summarized in Fig. 1 for Z from 60 (Nd) to 70 (Yb). The core electron temperatures corresponding to these spectra are in the range of 1.5–2.4 keV. As shown, the spectra are dominated by discrete feature with some isolated spectral lines which systematically moves to shorter wavelength as Z increases. Judging from the previous databases, these discrete lines mainly originate from n=4–4 transitions of Cu-like, Zn-like and Ga-like ions having relatively simple electron configurations.

For example, the lines of the $4p_{1/2}$–$4d_{3/2}$ transition of Cu-like ions are indicated by arrows in Fig. 1. The measured wavelengths of the lines are summarized in Table I together with the earlier experimental values[3]. Among them, the lines for Tb (Z=65), Ho (Z=67) and Tm (Z=69) have not been experimentally identified in earlier studies. Consequently, the present study gives the first experimental identification of the spectral lines of Cu-like ions for these elements. The wavelengths for the other elements are in excellent agreement with those in the earlier study.

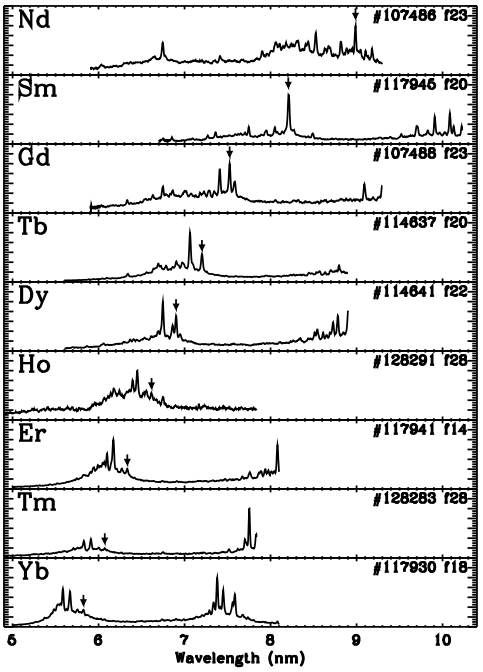

Fig. 1: Z dependence of EUV spectra measured under relatively high temperature conditions in LHD for the lanthanide elements with Z from 60 (Nd) to 70 (Yb). The line positions of the $4p_{1/2}$–$4d_{3/2}$ transition of Cu-like ions are marked by arrows.

Table I: Wavelengths in nm of the lines of $4p_{1/2}$–$4d_{3/2}$ transition of Cu-like ions measured in LHD and earlier experiments[3].

Z	element	LHD	previous[3]
60	Nd	8.987	8.9844
62	Sm	8.211	8.2206
64	Gd	7.524	7.5316
65	Tb	7.203	—
66	Dy	6.902	6.9080
67	Ho	6.614	—
68	Er	6.334	6.3403
69	Tm	6.072	—
70	Yb	5.824	5.8265

1) Sudo, S. and Tamura, N.: Rev. Sci. Instrum. **83** (2012) 023503.

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

3) Reder, J. and Luther, G.: Phys. Scr. **24** (1981) 732.