§15. Development of Wide Band and Compact X-Ray Spectrometer

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A wide band and compact X-ray spectrometer has been constructed to measure simultaneously the Kα X-ray transition array from all Fe ionization stages and to evaluate the charge state distribution in the plasma center. We started to develop the wide band and compact X-ray spectrometer from 2004 and installed the spectrometer at #1-O port on the LHD in 2005 Nov (Fig.1a). As the first step, we checked vacuum leakage of the spectrometer. Then, we regulated the alignments between a CCD detector and a crystal position using CCD 2D-image data of LHD plasmas. At present, the data are taken with a time interval of 10ms under a full vertical charge shift mode. Thus we have obtained the X-ray spectra in the wide energy range of 6.4-7.0keV from 2005 Nov to 2006 Feb., routinely.

The spectrometer consists of a Johan-type LiF(220) (Lithium Fluoride: 2d=2.848Å, Fig.1b) crystal and a back-illuminated CCD detector (Andor model DO420-BN)[1]. The energy resolution of the spectrometer has been evaluated using the He-like Fe Kα resonance line from LHD plasmas and estimated to be 10eV at 6.7keV as a value of FWHM.

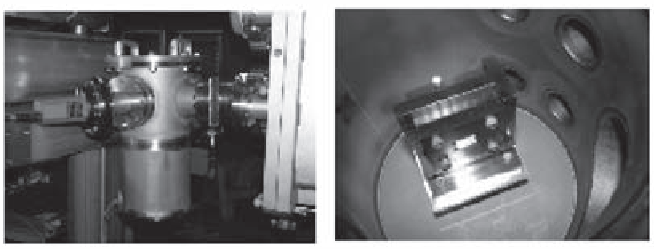

Fig.1 Photographs of (a: left) wide band and compact X-ray spectrometer and (b: right) Johann-type LiF(220) curved crystal set in crystal holder on rotary stage.

Figure 2 shows typical examples of Fe Kα spectra emitted from LHD plasmas with electron temperatures of 1.0keV (top) and 1.7keV (bottom). The electron temperature is measured with Thomson scattering diagnostic. It is seen that the dominant charge state of Fe ions at the plasma center moves from FeXXIII (Be-like) to FeXXV (He-like) according to the temperature. The impurity charge distribution is mainly a function of the electron temperature, but significantly affected by the radial transport coefficient. The relationship of the intensities of He-like and C-like Kα lines to the electron temperature is plotted in Fig.3. It should be noticed that the vertical axis is logarithmic. The temperature dependence of the Fe Kα lines is very strong and the experimentally obtained curves fundamentally express excitation rate coefficients to the Fe ions.

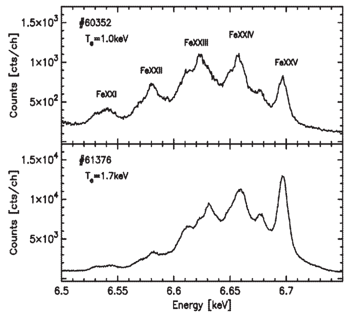

Fig.2 Typical examples of Fe Kα spectra observed with compact crystal spectrometer. (Top: shot number #60352, T_e=1.0keV, B=-2.789T, R_{ax}=3.55m; bottom: #61376, T_e=1.7keV, B=-2.750T, R_{ax}=3.60m).

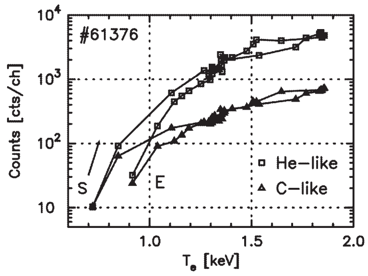

Fig.3 Relationship of Fe Kα line intensities to central electron temperature for He-like and C-like Fe ions. (S: start, E: End)

However, a small difference appears at temperatures lower than 1.3keV and the counts at last phase of the discharge become larger than at initial phase of the discharge. In LHD the density profile becomes peaked at the plasma decay phase suggesting an appearance of large inward flux. The difference originates in different central densities of electrons and Fe ions. Effective excitation coefficients of such Kα lines will be experimentally determined after detailed analysis.

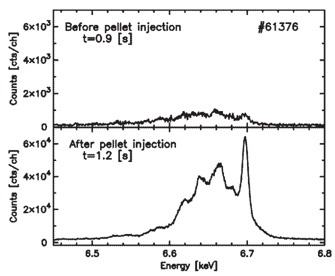

Fig.4 Fe Kα spectra before (top: t=0.9s) and after (bottom: t=1.2s) pellet injection (t=1.0s).

A carbon pellet ($0.9mm^{\phi} \times 0.9mm^{L}$) coated by iron with a thickness of 13μm was injected using an impurity pellet injector[2] to confirm the brightness of Fe Kα lines and to test the signal response. The pellet with a speed of 200m/s is ablated at the plasma center, at least within a half radius of the LHD plasma. The pellet was injected at 1.0s from the initiation of plasma. Figure 4 shows Kα spectra before (top: t=0.9s) and after (bottom: t=1.2s) pellet injection. It is understood from the figures that the Fe Kα intensities required in this measurement can be sufficiently obtained using the Fe-coated carbon pellet. This was a very important step in the present work. Any metallic impurities can be used for the observation by selecting a material for the coating.

Reference

1) I.Sakurai, Y.Tawara, C.Matsumoto et al., submitted to Rev. Sci. Instrum. (2006)
2) H.Nozato, S.Morita, M.Goto et al., Rev. Sci. Instrum. 74, 2032 (2003).