§7. Development of Wide Band and Compact X-ray Spectrometer

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A wide band and compact X-ray spectrometer has been developed 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. Although analysis of the charge state distributions of impurity ions can determine the transport coefficients, the Fe Kα X-ray line measurements became also important for understanding detailed processes on the ionization and recombination of highly ionized ions.

The X-ray spectrometer has been constructed using a Johan-type Lif (220) crystal (Lithium Fluoride, 2d=2.848Å) and a back-illuminated CCD detector (Andor model DO420-BN)[1] in Fig. 1. The spectrometer was installed at #1-O port on the LHD in 2005 Nov. The energy resolution of the spectrometer is 10eV at 6.7keV as a value of FWHM. Time-developed Fe Kα spectra were measured with a time interval of 10ms in the full binning mode of the CCD. We have been clearly observed the charge states distribution from Fe irons of FeXVIII to FeXXV excluding FeXXVI. The obtained data exhibit enough intensity. The impurity charge distribution of Kα spectra 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 obtained from X-ray spectra to the electron temperature is plotted in Fig.2. The electron temperature is measured with Thomson scattering diagnostic. 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 iron ions. 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 became peaked at the plasma decay phase suggesting an appearance of large inward flux. The difference originates in different central densities of electrons and iron ions. Effective excitation coefficients of such Kα lines will be experimentally determined after detailed analysis.

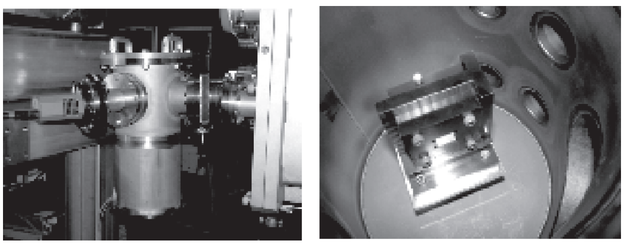

Fig.1 Photographs of (a: left) wide band and compact X-ray spectrometer and (b: right) Johann-type curved crystal set in crystal holder on rotary stage.

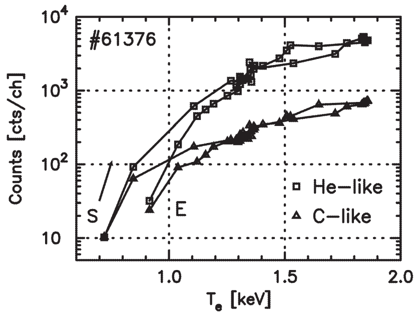

Fig.2. Relationship of Fe Kα line intensities to central electron temperature for He-like and C-like Fe ions. (S: start, E: End)

In the next step, the charge state distribution measurement is focused on the measurement of FeXVIII－XXV, we selected a quartz (2023) curved crystal (2d=2.7498 Å) with a curvature radius of 2R=630mm[2]. The size of the crystal is the same as the LiF crystal and the distance between the crystal and detector is 433mm. The accuracy of the crystal curvature was measured by a method of the non-contact three dimensional measurement techniques. The accuracy of the curvature radius is within 2R=630±0.5mm and a deviation from the circle is △R=±0.5 μ m. The expected energy range is 6.40 - 6.75keV and the energy dispersion is 0.4eV/ch. This new spectrometer has been installed at #1-O port at a distance of 9m from the plasma center in 2007 Jan. We started to measure the X-ray spectra from 2007 Feb. Figure 3 shows typical example of Fe Kα spectrum emitted from LHD plasmas with quartz (2023) crystal. The observed energy resolution of the spectrometer has been calculated using the He-like Fe Kα resonance line and estimated to be 4eV at 6.7keV as a value of FWHM. This resolution is enough high for the analysis of iron charge state distribution.

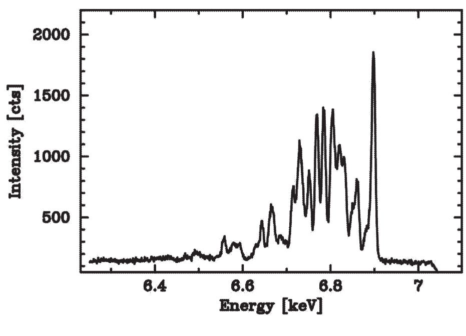

Fig.3. Typical example of Fe Kα spectrum observed with new spectrometer using quartz (2023) crystal.

References

1) I.Sakurai, Y.Tawara, C.Matsumoto et al., Sci. Instrum. **77**, (2006) 10F328.
2) I.Sakurai, Y.Tawara, C.Matsumoto et al., to be published in Plasma and Fusion Research (2007).